Tilo Strobach
Julia Karbach
Editors

Cognitive Training

An Overview of Features and Applications

Springer

Cognitive Training

Tilo Strobach • Julia Karbach
Editors

Cognitive Training

An Overview of Features and Applications

Springer

Editors
Tilo Strobach
Department of Psychology
Medical School Hamburg
Hamburg, Germany

Julia Karbach
Department of Psychology
Goethe-University Frankfurt
Frankfurt/Main, Germany

ISBN 978-3-319-42660-0 ISBN 978-3-319-42662-4 (eBook)
DOI 10.1007/978-3-319-42662-4

Library of Congress Control Number: 2016953131

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Contents

Part I Basic Concepts and Methodology

Part II Plasticity in Different Age Groups

Part III Plasticity of Different Cognitive Domains

Part IV Multidomain Trainings

Part V Cognitive Training in Applied Contexts

Part VI Outlook

About the Editors

Tilo Strobach finished his doctoral degree at Humboldt University of Berlin. After that, he held postdoc positions at this university and at Ludwig Maximilians University Munich. Currently, Tilo Strobach is full professor for cognitive psychology at the Medical School Hamburg. His research focuses on the analysis of cognitive plasticity as a result of training (e.g., video-game, dual-task, working memory, and task-switching training) and cognitive aging. Furthermore, he aims at specifying the cognitive processing architecture in situations that demand executive functions as well as the perception of complex objects.

Julia Karbach is a developmental cognitive psychologist holding a Ph.D. in Psychology from Saarland University. She currently serves as full professor at Goethe-University Frankfurt. Her research interests include neurocognitive development and plasticity across the life span, psychocardiology, and the prediction of academic achievement from primary to tertiary education. Her work has been published in numerous leading peer-reviewed international journals.

Contributors

Tracy Packiam Alloway Department of Psychology, University of North Florida, Jacksonville, FL, USA

Claudia C. von Bastian Cognition and Cognitive Neuroscience Research Centre, Department of Psychology, Bournemouth University, Bournemouth, England

Daphne Bavelier Department of Psychology, University of Geneva, Geneva, Switzerland

Sylvie Belleville Research Center, Institut Universitaire de Gériatrie de Montréal, Université de Montréal, Montréal, QC, Canada

Louis Bherer PERFORM Centre and Psychology Department, Concordia University, Montreal, QC, Canada

Benjamin Boller Research Center, Institut Universitaire de Gériatrie de Montréal, Université de Montréal, Montréal, QC, Canada

Martin Buschkuehl MIND Research Institute, Irvine, CA, USA

Lorenza S. Colzato Cognitive Psychology Unit, Leiden Institute for Brain and Cognition, Leiden University, Leiden, The Netherlands

Lina M. Cómbita Department of Experimental Psychology, Center for Research on Mind, Brain, and Behavior (CIMCYC), University of Granada, Granada, Spain

Michael Falkenstein Leibniz Research Centre for Working Environment and Human Factors at TU Dortmund (IfADo), Dortmund, Germany

Institute for Ageing Learning and Occupation (ALA), Bochum, Germany

Andrea N. Frankenstein Department of Psychology, University of North Florida, Jacksonville, FL, USA

Patrick D. Gajewski Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund, Germany

Thomas Gorman Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA

C. Shawn Green Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA

Sabrina Guye University Research Priority Program (URPP) “Dynamics of Healthy Aging”, University of Zurich, Zurich, Switzerland

Bernhard Hommel Cognitive Psychology Unit, Leiden Institute for Brain and Cognition, Leiden University, Leiden, The Netherlands

Susanne Jaeggi School of Education, University of California, Irvine, CA, USA

Masha R. Jones School of Education, University of California, Irvine, CA, USA

Julia Karbach Department of Psychology, Goethe-University Frankfurt, Frankfurt/Main, Germany

Benjamin Katz Department of Psychology, University of Michigan, Ann Arbor, MI, USA

Tanja Könen Department of Psychology, Goethe-University Frankfurt, Frankfurt, Germany

Jutta Kray Department of Psychology, Saarland University, Saarbrücken, Germany

Mike Martin University Research Priority Program (URPP) “Dynamics of Healthy Aging”, University of Zurich, Zurich, Switzerland

Division of Gerontopsychology, Department of Psychology, University of Zurich, Zurich, Switzerland

Mark A. McDaniel Department of Psychological and Brain Sciences, Washington University in St. Louis, St. Louis, MO, USA

Susan Mérillat University Research Priority Program (URPP) “Dynamics of Healthy Aging,” University of Zurich, Zurich, Switzerland

Kristell Pothier PERFORM Centre and Psychology Department, Concordia University, Montreal, QC, Canada

Joan P. Pozuelos Department of Experimental Psychology, Center for Research on Mind, Brain, and Behavior (CIMCYC), University of Granada, Granada, Spain

Tyler Robinson Department of Psychology, University of North Florida, Jacksonville, FL, USA

Christina Röcke University Research Priority Program (URPP) “Dynamics of Healthy Aging”, University of Zurich, Zurich, Switzerland

M. Rosario Rueda Department of Experimental Psychology, Center for Research on Mind, Brain, and Behavior (CIMCYC), University of Granada, Granada, Spain

E. Glenn Schellenberg Department of Psychology, University of Toronto Mississauga, Mississauga, ON, Canada

Florian Schmiedek German Institute for International Educational Research (DIPF), Frankfurt am Main, Germany

Torsten Schubert Department of Psychology, Martin Luther University Halle, Halle, Germany

Priti Shah Department of Psychology, University of Michigan, Ann Arbor, MI, USA

Yee Lee Shing Center for Lifespan Psychology, Max Planck Institute for Human Development, Berlin, Germany

Division of Psychology, University of Stirling, Scotland, UK

Tilo Strobach Department of Psychology, Medical School Hamburg, Hamburg, Germany

Swathi Swaminathan Department of Psychology, University of Toronto Mississauga, Mississauga, ON, Canada

Niels A. Taatgen University of Groningen, Groningen, The Netherlands

Joan Toglia School of Health and Natural Sciences, Mercy College, Dobbs Ferry, New York, NY, USA

Sharda Umanath Department of Psychology, Claremont McKenna College, Claremont, CA, USA

Laura Prieto del Val Department of Physiology, Anatomy, and Cellular Biology, Pablo de Olavide University, Sevilla, Spain

Paul Verhaeghen School of Psychology, Georgia Institute of Technology, Atlanta, GA, USA

Elisabeth Wenger Center for Lifespan Psychology, Max Planck Institute for Human Development, Berlin, Germany

Introduction

Tilo Strobach and Julia Karbach

Throughout the entire life span, individuals are required to adapt to the demands of changing contexts and dynamic social environments. The potential modifiability of a person's cognitive and neural system resulting from these adaptations has been referred to as cognitive and neural plasticity. One way to understand this plasticity is to apply training interventions and to measure the scope of their effects in order to identify the mechanisms underlying plastic changes in mind and brain (see Hertzog et al. 2008; Karbach and Schubert 2013; Lustig et al. 2009; Schubert et al. 2014, for reviews).

Over the last decades, the literature on cognitive training interventions has been growing rapidly, demonstrating that cognitive training is a timely issue of high academic as well as societal relevance. For instance, a literature search for "cognitive training" in the abstracting and indexing databases PsychINFO and PubMed by February 19, 2016, demonstrated a total of about 1.407 peer-reviewed contributions since 1966/1.217 peer-reviewed contributions since 1973, respectively. Both databases demonstrate that more contributions on cognitive training were published between 2010 and 2016 than in the more than 40 years before that (1966–2010). These impressive numbers raise the question why research on cognitive training became so popular in the second decade of this century?

Several factors may have contributed to this development. First—and this certainly influenced many psychological disciplines, including cognitive and experimental psychology—recent decades were characterized by tremendous technical

---

T. Strobach (✉)
Department of Psychology, Medical School Hamburg,
Hamburg, Germany
e-mail: tilo.strobach@medicalschool-hamburg.de

J. Karbach
Department of Psychology, Goethe-University Frankfurt, Frankfurt/Main, Germany
e-mail: karbach@psych.uni-frankfurt.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_1

advances. These technical advances also had a large impact on cognitive training research. For instance, they led to computerized experimental setups allowing to precisely assess changes in both behavior and neural processing; such precise assessments may be particularly relevant for demonstrating the sometimes rather small effects sizes in cognitive training studies. Further, technical advances also allow the efficient handling and sophisticated analyses of large longitudinal data sets that are very common in studies with extensive training protocols including numerous experimental sessions and groups of participants. With state-of-the-art software, data cannot only be analyzed at the group level but training-induced changes can also be modeled at the individual and latent level.

Second, interest in cognitive training has been spurred tremendously by findings showing that cognitive and neural plasticity are present up to very old age. Earlier accounts assumed that the brain is capable of significant plastic changes only early in life and becomes impervious to change afterwards (e.g., Wiesel and Hubel 1965), suggesting that basic processing capacities cannot be improved by training after early adulthood. However, recent work has clearly established that plasticity is not only present up to very old age (Bavelier et al. 2010; Green et al. 2014; Hertzog et al. 2008) but that the mind and brain of older adults can be as plastic as in young adults (Karbach and Verhaeghen 2014, for a meta-analysis).

Another widely discussed issue in the field of cognitive training research is the "curse of specificity," that is, the transferability of training-induced performance gains to untrained tasks and abilities (Green and Bavelier 2008; Strobach et al. 2014). Early cognitive training studies showed that while individuals improved their performance on a task given appropriate training, little to no benefits of this training were seen on new tasks (even if they were seemingly similar to the trained task). Such task-specific learning has been shown in nearly all fields of psychology from motor control, to problem-solving, reasoning, general cognition, and education (Ball and Sekuler 1982; Barnett and Ceci 2002; Detterman and Sternberg 1993; Fahle 2004; Schmidt and Bjork 1992). Nevertheless, recent work suggests that training can indeed produce broad, generalizable effects. In fact, examples of general transfer effects are frequently reported in the literature, especially after cognitive training interventions focusing on basic processing capacities, such as working memory or executive functions (see Au et al. 2015; Hindin and Zelinski 2012; Karbach and Verhaeghen 2014; Karr et al. 2014; Schwaighofer et al. 2015, for meta-analyses). Moreover, playing video games of the "action video game" genre has been shown to improve a variety of cognitive skills (e.g., Li et al. 2009; Strobach et al. 2012; see Toril et al. 2014, for a meta-analysis). Aside from these cognitive trainings, there is also ample evidence for positive effects of musical training (Schellenberg 2004) and particularly physical training (see Bherer et al. 2013, for a review and Colcombe and Kramer 2003, for a meta-analysis) on cognitive abilities across a wide range of ages.

At this point in cognitive training research (50 years after the first publications in the domain of "cognitive training" according to PsycINFO), we aimed at summing up the current state of findings of this first era of cognitive training research. From our perspective, this era is generally characterized as a rather heterogeneous phase in which (1) many studies on cognitive research were published that included a variety of designs, methods, and training protocols which unsurprisingly yielded very mixed findings and (2) studies were often less theory driven and theoretical models describing the mechanisms underlying training and effects are mostly missing. Therefore, we aimed at integrating the state-of-the-art of different domains in the field of cognitive training research accompanied by theoretical models describing the mechanisms underlying training and transfer effects.

The first section of this book covers basic concepts, theory, and methodological issues from a very general perspective (i.e., relevant for different populations, age groups, and cognitive domains). Hence, Taatgen (this volume) presents and elaborates general theoretical models of training and transfer effects. Researchers who investigate these effects can draw on a well-established methodology for the evaluation of psychological interventions. Doing so, they face the equally well-established long list of critical issues, reducing the validity of findings in studies on cognitive training. Therefore, Schmiedek (this volume) discusses the most common and relevant issues as well as possible methodological solutions.

Cognitive training is relevant throughout the entire life span. Thus, the second section of this book elaborates on the cognitive and neural plasticity in different age groups from a developmental perspective. Since effective cognitive skills are key to learning, socialization, and success to a wide range of real-world outcomes, Rueda et al. (this volume) present the great body of literature on the extent to which cognitive skills can be enhanced through training interventions during childhood and adolescence. Furthermore, probably the most prominent way of applying cognitive training is to use it as a tool against age-related decline in cognitive abilities. Guye et al. (this volume) illustrate promising avenues in this domain.

After starting with general perspectives on theory, methodology, and age groups of cognitive training, the third section provides details regarding specific cognitive domains targeted during training. Several prominent types of domain-specific training focused on memory training. Therefore, training and transfer effects are reviewed in the domain of working memory (Könen et al. this volume), episodic memory (Wenger and Shing this volume), and prospective memory (Umanath et al. this volume). The other training domain targeting higher-cognitive processes is executive functions (Karbach and Kray this volume).

Similar to the third section, the fourth section is structured by the type of training. However, in contrast to the theoretically well-defined training domains presented in section three, the chapters of this section are structured by more superficial characteristics. While trainings discussed in these chapters may look very similar, they often tap different cognitive domains (multi-domain training). For instance, video game training—more specifically "action video games"—is characterized by complex visual displays, fast-paced speed, as well as motivational elements. Therefore, Green et al. (this volume) discuss the effects of playing these games on perception and attentional control, while Strobach and Schubert (this volume) rather focus on potential influences of action video game playing on executive functions. The following chapters cover the effects of mindfulness training (Verhaeghen this volume), music training (Swaminathan and Schellenberg this volume), and physical training (Pothier and Bherer this volume), respectively.

The focus of the fifth book section is on the applied perspective. Katz et al. (this volume) present the state-of-the-art regarding individual differences in the effectiveness of cognitive training and the role of motivational processes. Promising ways to apply cognitive training, especially working memory training, in the educational context are discussed by Alloway et al. (this volume). Focusing on cognitive training as a tool against age-related decline in cognitive abilities, Falkenstein and Gajewski (this volume) summarize training-related neurophysiological changes in older adults and relate them to a discussion of data from EEG training studies with elderly workers. Also with a focus on older adults, Belleville et al. (this volume) present different types of cognitive training and show their training and transfer effects in patients with mild cognitive impairments (MCI).

While the previous sections largely focus on past findings in cognitive training research with a strong theoretical perspective, the final section draws conclusions for future research. That is, Colzato and Hommel (this volume) discuss future developments in this area. For instance, they emphasize the need to develop more specific theories guiding cognitive training programs. With this emphasis, they conclude the theoretical perspective of this book and pave the way for future studies on the effects of cognitive training.

The area of cognitive training is a dynamically and fast-growing research area that is increasingly incorporated into scientific teaching and education. The sections of this book should provide comprehensive overviews of state-of-the-art research in cognitive training. They address students and researchers of all academic levels (i.e., from undergraduates to professors) as well as professionals in applied contexts (e.g., teachers, clinicians) by outlining empirical findings and methodological approaches of cognitive training research in different populations, age groups, and cognitive domains. We hope that this volume not only serves to summarize the current state of research but also inspires new exiting, well-designed, and informative studies in this fast-growing scientific field. One of the largest potentials in this area of research lies in the fact that it is very multidisciplinary, integrating research from cognitive, neuropsychological, developmental, educational, and medical science on a theoretical, methodological, and applied level. We believe that this potential may be used in future studies to uncover the cognitive and neural mechanisms underlying training-induced performance benefits and to design adaptive, individually tailored training interventions that can by applied in various contexts, including scientific, educational, and clinical settings.

References

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: A meta-analysis. *Psychonomic Bulletin & Review, 22*(2), 366–377.

Ball, K., & Sekuler, R. (1982). A specific and enduring improvement in visual motion discrimination. *Science, 218*(4573), 697–698.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn?: A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612–637.

Bavelier, D., Levi, D. M., Li, R. W., Dan, Y., & Hensch, T. K. (2010). Removing brakes on adult brain plasticity: From molecular to behavioral interventions. *The Journal of Neuroscience, 30*(45), 14964–14971.

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research, 2013*, Article ID 657508. doi:10.1155/2013/657508

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults a meta-analytic study. *Psychological Science, 14*(2), 125–130.

Detterman, D. K., & Sternberg, R. J. (1993). *Transfer on trial: Intelligence, cognition, and instruction*. Westport: Ablex.

Fahle, M. (2004). Perceptual learning: A case for early selection. *Journal of Vision, 4*(10), 879–890.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: A review of human brain plasticity and training-induced learning. *Psychology and Aging, 23*(4), 692–701.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*(6), 756–772.

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2008). Enrichment effects on adult cognitive development can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9*(1), 1–65.

Hindin, S. B., & Zelinski, E. M. (2012). Extended practice and aerobic exercise interventions benefit untrained cognitive outcomes in older adults: A meta-analysis. *Journal of the American Geriatrics Society, 60*(1), 136–141.

Karbach, J., & Schubert, T. (2013). Training-induced cognitive and neural plasticity. *Frontiers in Human Neuroscience, 9*, 6.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work a meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*(11), 2027–2037.

Karr, J. E., Areshenkoff, C. N., Rast, P., & Garcia-Barrera, M. A. (2014). An empirical comparison of the therapeutic benefits of physical exercise and cognitive training on the executive functions of older adults: A meta-analysis of controlled trials. *Neuropsychology, 28*(6), 829–845.

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience, 12*(5), 549–551.

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: A review and future directions. *Neuropsychology Review, 19*(4), 504–522.

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science, 15*(8), 511–514.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science, 3*(4), 207–217.

Schubert, T., Strobach, T., & Karbach, J. (2014). New directions in cognitive training: On methods, transfer, and application. *Psychological Research, 78*(6), 749–755.

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist, 50*(2), 138–166.

Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*(1), 13–24.

Strobach, T., Salminen, T., Karbach, J., & Schubert, T. (2014). Practice-related optimization and transfer of executive functions: A general review and a specific realization of their mechanisms in dual tasks. *Psychological Research, 78*(6), 836–851.

Toril, P., Reales, J. M., & Ballesteros, S. (2014). Video game training enhances cognition of older adults: A meta-analytic study. *Psychology and Aging, 29*(3), 706–716.

Wiesel, T. N., & Hubel, D. H. (1965). Comparison of the effects of unilateral and bilateral eye closure on cortical unit responses in kittens. *Journal of Neurophysiology, 28*(6), 1029–1040.

Part I

Basic Concepts and Methodology

Methods and Designs

Florian Schmiedek

Introduction

Researchers who aim to investigate the effectiveness of cognitive trainings can draw on well-established methodology for the evaluation of behavioral interventions in psychology and education (Murnane and Willett 2010; Shadish et al. 2002). Doing so, they face a long list of potential issues that can be characterized as threats to different types of the validity of findings. Here, the most common and relevant threats, as well as possible methodological approaches and study design elements to reduce or rule out these threats in the context of cognitive training studies, will be discussed.

The commonly preferred design for investigating cognitive training interventions is one with random assignment of a sample of participants to training and control groups with pre- and posttest assessments of a selection of tasks chosen to represent one or more cognitive abilities that the training might potentially improve. Significantly larger average improvements on such outcome measures in the training than in a control group are taken as evidence that the training benefits cognition. Such a design indeed clears out a number of potential issues. Certain problems that arise when evaluating cognitive trainings, however, require solutions that go beyond, or modify, commonly used of-the-shelf study design elements. For example, the inclusion of no-treatment control groups for ruling out threats to internal validity and the use of single tasks as outcome measures of transfer effects are associated with certain deficits. In the following, methodological problems and challenges will be discussed along the established typology of statistical conclusion validity, internal and external validity, as well as construct validity (Shadish et al. 2002).

F. Schmiedek (✉)
German Institute for International Educational Research (DIPF),
Frankfurt am Main, Germany
e-mail: schmiedek@dipf.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_2

Statistical Conclusion Validity

Statistical conclusion validity refers to whether the association between the treatment and the outcome can be reliably demonstrated. Such demonstration is based on inferential statistics, which can provide evidence that observed differences between experimental groups in posttest scores, or in pretest-to-posttest changes, are unlikely to be due to sampling error (i.e., one group having higher scores simply by chance). Given that existing training studies mostly have relatively small sample sizes (with experimental groups of more than 30–40 participants being rare exceptions), the statistical power to do so often is low, and findings are in danger of being difficult to replicate and being unduly influenced by outliers and violations of statistical assumptions.

Furthermore, and in light of recent discussions about the replicability of findings and deficient scientific standards in psychological research (e.g., Maxwell et al. 2015), there is the problem that low power might increase researchers' propensity to lapse into fishing-for-effect strategies. Given that (a) the researchers' desired hypothesis often will be that a training has a positive effect, (b) training studies are resource-intensive, and (c) the non-registered analysis of data allows for a number of choices of how exactly to be conducted (Fiedler 2011), it has to be considered a danger that such choices (like choosing subsamples or subsets of outcome tasks) are made post hoc in favor of "finding" significant effects and thereby invalidate results of inferential test statistics. In combination with publication biases that favor statistically significant over nonsignificant results, such practices in a field with typically low power could lead to a distorted picture of training effectiveness, even in meta-analyses. A general skepticism should therefore be in place regarding all findings that have not been replicated by independent research groups. Regarding the danger of fishing-for-effects practices, preregistration of training studies, including the specific hypotheses and details of data preparation and analysis, are a possible solution, which is well established in the context of clinical trials. In general, effort should be invested to increase statistical power and precision of effect size estimates. Besides large enough sample sizes, this also includes ensuring high reliability of outcome measures and of treatment implementation.

Internal Validity

Internal validity, that is, a study's ability to unambiguously demonstrate that the treatment has a causal effect on the outcome(s), deserves getting a strong weight when judging the quality of intervention studies. It involves ruling out alternative explanations for within-group changes (including, e.g., practice effects, maturation, or statistical regression to the mean from pretest to posttest) and/or between-group differences (e.g., systematic selection effects into the treatment condition). Common reactions to these problems are requests to (a) use a control group that allows to estimate the size of the effects due to alternative explanations and (b) randomly assign participants into the different groups. While intact random assignment assures that the mean differences between groups can be unbiased estimates of the *average causal effect* of the treatment (Holland 1986), several cautionary notes are at place regarding this "gold standard" of intervention studies.

First, the unbiasedness of the estimate refers to the expected value. This does not rule out that single studies (particularly if sample sizes are small) have groups that are not well comparable regarding baseline ability or other person characteristics that might interact with the effectiveness of the training. Therefore, the amount of trust in effect size estimates should only be high for studies with large samples or for replicated (meta-analytic) findings. For single studies with smaller samples, matching techniques based on pretest scores can help to reduce random differences between groups that have an effect on estimates of training effects.

Second, the benefits of randomization get lost if the assignment is not "intact," that is, if participants do not participate in the conditions they are assigned to or do not show up for the posttest. Such lack of treatment integrity or test participation can be associated with selection effects that turn an experiment into a quasi-experiment—with all the potential problems of confounding variables that can affect the estimate of outcome differences.

Third, formal analysis of causal inference based on randomized treatment assignment (Holland 1986) shows that the interpretation of mean group differences as average causal effects is only valid if participants do not interact with each other in ways that make individual outcomes dependent on whether or not particular other participants are assigned to the treatment or the control condition. While this is unlikely to pose a problem if training is applied individually, it could be an issue that has received too little attention in studies with group-based interventions—where interactions among participants might, for example, influence motivation.

Whenever treatment assignment cannot be random, due to practical or ethical considerations, or when randomization breaks down during the course of the study, careful investigation of potential selection effects is required. This necessitates the availability of an as-complete-as-possible battery of potential confounding variables at pretest. If analyses of such variables indicate group differences, findings cannot unambiguously be attributed to the treatment. Attempts to remedy such group differences with statistical control techniques is associated with strong conceptual (i.e., exhaustiveness of the available information regarding selection effects) and statistical assumptions (e.g., linearity of the relation with the outcome) and should therefore be regarded with great caution. An alternative to regression-based control techniques is post hoc matching and subsample selection based on propensity score analyses (Guo and Fraser 2014). This requires sample sizes that are typically not available in cognitive training research, however. Beneficial alternative design approaches for dealing with situations in which randomization is not possible, or likely to not stay intact, are available, like regression discontinuity designs or instrumental variable approaches (Murnane and Willett 2010), but have received little attention in cognitive training research so far.

Construct Validity

While the demonstration of causal effects of the treatment undoubtedly is a necessity when evaluating cognitive trainings, a strong focus on internal validity and randomization should not distract from equally important aspects of construct validity. Addressing the question of whether the investigated variables really represent the theoretical constructs of interest, construct validity is relevant for both, the treatment and the outcome measures.

Regarding the treatment, high internal validity does only assure that one or more aspects that differentiate the treatment from the control condition causally influence the outcome. It does not tell which aspect of the treatment it is, however. Given the complexity of many cognitive training programs and the potential involvement of cognitive processes as well as processes related to motivation, self-concept, test anxiety, and other psychological variables in producing improvements in performance, the comparison to so-called *no-contact control conditions* typically cannot exclude a number of potential alternative explanations of why an effect has occurred. In the extreme case, being in a no-contact control condition and still having to re-do the assessment of outcome variables at posttest is so demotivating that performance in the control group declines from pre- to posttest. Such a pattern has been observed in several cognitive training studies and renders the interpretation of significant interactions of group (training vs. control) and occasion (pretest vs. posttest) as indicating improved cognitive ability very difficult to entertain (Redick 2015). As from a basic science perspective, the main interest is in effects that represent plastic changes of the cognitive system, “active” control conditions therefore need to be designed, which are able to produce the same non-focal effects, but do not contain the cognitive training ingredient of interest. This is a great challenge, however, given the number and complexity of cognitive mechanisms that potentially are involved in processing of, for example, working memory tasks and that can be affected by trainings (von Bastian and Oberauer 2014). For many of these mechanisms, like the use of certain strategies, practice-related improvements are possible, but would have to be considered exploitations of existing behavioral flexibility, rather than extensions of the range of such behavioral flexibility (Lövdén et al. 2010). If motivational effects are partly due to the joy of being challenged by complex tasks, it also will be difficult to invent tasks of comparably joyful complexity but little demand on working memory. In addition to inventive and meticulous creation of control conditions, it is therefore necessary to assess participants’ expectations, task-related motivation, and noncognitive outcomes, before, during, and after the intervention.

Regarding the outcome variables, construct validity needs to be discussed in light of the issue of transfer distance and the distinction between skills and abilities. When the desired outcome of a training is the improvement of a specific skill or the acquisition of a strategy tailored to support performing a particular kind of task, the assessment of outcomes is relatively straightforward—it suffices to measure the trained task itself reliably at pre- and posttest. As the goal of cognitive trainings typically is to improve an underlying broad ability, like fluid intelligence or episodic memory, demonstrating improvements on the practiced tasks is not sufficient, however, as those confound potential changes in ability with performance improvements due to the acquisition of task-specific skills or strategies. It is therefore common practice to employ transfer tasks that represent the target ability but are different from the trained tasks. The question of how different such transfer tasks are from the trained ones is often answered using arguments of face validity and classifications as “near” and “far” that are open to criticism and difficult to compare across studies. What seems far transfer to one researcher might be considered near transfer by another one. Particularly if only single tasks are used as outcome measure for a cognitive ability, it is difficult to rule out alternative explanations that explain improvements with a task-specific *skill*, rather than with improvements in the underlying *ability* (see, e.g., Hayes et al. 2015, or Moody 2009).

The likelihood of such potential alternative explanations can be reduced if the abilities that a training is thought to improve are operationalized with several heterogeneous tasks that all have little overlap with the trained tasks and are dissimilar from each other in terms of paradigm and task content. The analysis of effects can then be conducted on the shared variance of these tasks, preferably using confirmatory factor models. This allows to analyze transfer at the level of latent factors that represent the breadth of the ability construct, replacing the arbitrary classification of “near vs. far” with one that defines “narrow” or “broad” abilities by referring to well-established structural models of cognitive abilities (Noack et al. 2009). If transfer effects can be shown for such latent factors, this renders task-specific explanations less likely.

External Validity

External validity encompasses the generalizability of a study’s results to other samples, as well as to other contexts, variations of the intervention’s setting, and different outcome variables. As few training studies are based on samples that are representative for broad populations, mostly little is known regarding generalizability to different samples. Furthermore, as findings for certain training programs are only rarely replicated by independent research groups, we only have very limited evidence so far regarding the impact of variations of the context, setting, and of the exact implementation of cognitive trainings. As one rare exception, the Cogmed working memory training (http://www.cogmed.com/) has been evaluated in number of studies by different research groups and with diverse samples. This has resulted in a pattern of failed and successful replications of effects that has been reviewed as providing little support for the claims that have been raised for the program (Shipstead et al. 2012a).

Similarly, generalizations of effects for certain transfer tasks to real-life cognitive outcomes, like everyday competencies and educational or occupational achievement, are not warranted, unless shown with direct measures of these outcomes.

Even if transfer tasks are known to have strong predictive validity for certain outcomes, this does not ensure that *changes* in transfer task performance show equally strong relations to *changes* in the outcomes (Rode et al. 2014). Finally, relatively little is known about maintenance and long-term effects of cognitive trainings. Here, the combination of training interventions and longitudinal studies would be desirable. In sum, there is a need for studies that reach beyond the typically used convenience samples and laboratory-based short-term outcomes, as well as beyond research groups' common practice of investigating their own pet training programs—to explore the scope, long-term effects, and boundary conditions of cognitive trainings in a systematic way.

Data Analysis

The standard data-analytical approach to the pretest–posttest control-group design in most studies still is a repeated measures ANOVA with *group* (training vs. control) as a between- and *occasion* (pretest vs. posttest) as a within-subject factor, and with a significant interaction of the two factors taken as evidence that observed larger improvements in the training than in the control group indicate a reliable effect of treatment. If there is interest in individual differences in training effects (Katz et al. this volume), either subgroups or interactions of the within-factor with covariates are analyzed. This approach comes with a number of limitations, however.

First, the associated statistical assumptions of sphericity and homogeneity of (co)variances across groups might not be met. For example, when a follow-up occasion (months or years after training) is added, sphericity is unlikely to hold across the unequally spaced time intervals. When the training increases individual differences in performance more than the control condition, homogeneity of variances might not be provided. Second, participants with missing data on the posttest occasions have to be deleted listwise (i.e., they are completely removed from the analysis). Third, analyses have to be conducted on a single-task level. This means that unreliability of transfer tasks can bias results and that, if several transfer tasks for the same ability are available, analyses have to be conducted either one by one or on some composite score.

All these potential problems can be cleared out by basing analyses on a structural equation modeling framework and using latent change score models (McArdle 2009). Provided large enough samples, multigroup extensions of these models (Fig. 1) allow testing all the general hypotheses typically addressed with repeated measures ANOVA—and more—while having several advantages: First, assumptions of sphericity and homogeneity of (co)variances are not necessary, as (co)variances are allowed to vary across groups and/or occasions. Second, parameter estimation based on full information maximum likelihood allows for missing data. If there are participants who took part in the pretest but dropped

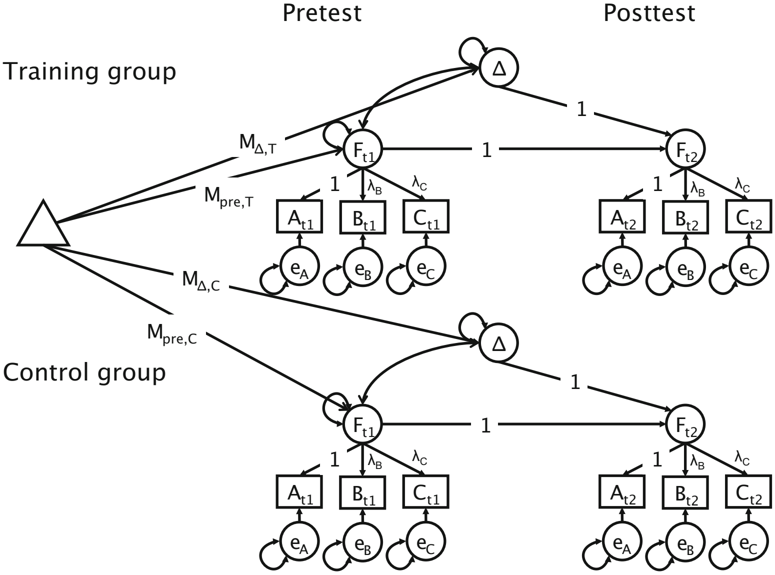

Fig. 1 Two-group latent change score model for pretest–posttest changes in a cognitive training study. Changes are operationalized as the latent difference (Δ) between latent factors at pretest (F_{t1}) and posttest (F_{t2}). These factors capture the common variance of a set of indicator tasks (A, B, and C). Ideally, factor loadings (λ), variances of the residual terms (e), and task intercepts (not shown) are constrained to be equal across groups and occasions (i.e., strict measurement invariance). Based on this model, hypotheses regarding group differences in pretest mean levels (M_{Pre}) and mean changes from pre- to posttest (M_{Δ}) can be investigated, as well as hypotheses regarding the variance and covariance of individual differences in pretest levels and changes (*double-headed curved arrows* on latent factors)

out from the study and did not participate in the posttest, their pretest score can still be included in the analysis and help to reduce bias of effect size estimates due to selective dropout (Schafer and Graham 2002). Third, change can be analyzed using latent factors. This has the advantage that effects can be investigated with factors that (a) capture what is common to a set of tasks that measure the same underlying cognitive ability and (b) are free of measurement error. This provides estimates of training effects that are not biased by unreliability of tasks. It also allows investigating individual differences in change in a way that is superior to the use of individual differences scores, which are known to often lack reliability. For example, the latent change score factor for a cognitive outcome could be predicted by individual differences in motivation, be used to predict other outcomes (e.g., wellbeing), or be correlated with latent changes in other trained or transfer tasks (e.g., McArdle and Prindle 2008).

Furthermore, these models can be extended using the full repertoire of options available in advanced structural equation models. These include multilevel analysis (e.g., to account for the clustering of participants in school classes), latent class analysis (e.g., to explore the presence of different patterns of improvements on a set of tasks), item response models (e.g., to model training-related changes at the level of responses to single items), and more.

Besides a lack of awareness of these advantages, three requirements of latent change score models might explain why they have been used relatively little in cognitive training research so far (Noack et al. 2014). First, these models typically require larger sample sizes than those available in many training studies. When analyzed in a multigroup model with parameter constraints across groups, however, it may be sufficient to have smaller sample sizes in each group than those typically requested for structural equation modeling with single groups. Second, the models require measurement models for the outcome variables of the training. As argued above, operationalizing outcomes as latent variables with heterogeneous task indicators also has conceptual advantages. If only single tasks are available, it still might be feasible to create a latent factor using parallel versions of the task (e.g., based on odd and even trials) as indicator variables. Third, these measurement models need to be invariant across groups and occasions to allow for unequivocal interpretation of mean changes and individual differences therein at the latent factor level (Vandenberg and Lance 2000). This includes equal loadings, intercepts, and preferably also residual variances, of indicator variables. While substantial deviations from measurement invariance can prohibit latent change score analyses, they at the same time can be highly informative, as they can indicate the presence of task-specific effects.

Summary and Outlook

The field of cognitive training research is likely to stay active, due to the demands from societies with growing populations of older adults and attempts to improve the fundamentals of successful education and lifelong learning. As reviewed along the different validity types, this research faces a list of challenges, to which still more could be added (for other methodological reviews and recently discussed issues, see Boot and Simons 2012; Green et al. 2014; Schubert and Strobach 2012; Shipstead et al. 2012b; Tidwell et al. 2014). At the same time, awareness of the methodological issues seems to be increasing so that there is reason to be optimistic that evaluation criteria for commercial training programs (like preregistration of studies) will be established, methodological standards regarding research design will rise, and available advanced statistical methods and new technological developments (like ambulatory assessment methods to assess outcomes in real-life contexts) will be used. Together with basic experimental and neuroscience research on the mechanisms underlying plastic changes in cognition, this should lead to better understanding of whether, how, and under which conditions different cognitive training interventions produce desirable effects.

References

Boot, W. R., & Simons, D. J. (2012). Advances in video game methods and reporting practices (but still room for improvement): A commentary on Strobach, Frensch, and Schubert (2012). *Acta Psychologica, 141*, 276–277. doi:10.1016/j.actpsy.2012.06.011.

Fiedler, K. (2011). Voodoo correlations are everywhere—Not only in neuroscience. *Perspectives on Psychological Science, 6*, 163–171. doi:10.1177/1745691611400237.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*, 756–772. doi:10.1007/s00426-013-0535-3.

Guo, S., & Fraser, W. M. (2014). *Propensity score analysis: Statistical methods and applications*. Thousand Oaks, CA: Sage.

Hayes, T. R., Petrov, A. A., & Sederberg, P. B. (2015). Do we really become smarter when our fluid-intelligence test scores improve? *Intelligence, 48*, 1–14. Retrieved from http://dx.doi.org/10.1016/j.intell.2014.10.005.

Holland, P. W. (1986). Statistics and causal inference. *Journal of the American Statistical Association, 81*(396), 945–960.

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136*, 659–676. doi:10.1037/a0020080.

Maxwell, S. E., Lau, M. Y., & Howard, G. S. (2015). Is psychology suffering from a replication crisis? What does "failure to replicate" really mean? *American Psychologist, 6*, 487–498. Retrieved from http://dx.doi.org/10.1037/a0039400.

McArdle, J. J. (2009). Latent variable modelling of differences and changes with longitudinal data. *Annual Review of Psychology, 60*, 577–605. doi:10.1146/annurev.psych.60.110707.163612.

McArdle, J. J., & Prindle, J. J. (2008). A latent change score analysis of a randomized clinical trial in reasoning training. *Psychology and Aging, 23*, 702–719. doi:10.1037/a0014349.

Moody, D. E. (2009). Can intelligence be increased by training on a task of working memory? *Intelligence, 37*, 327–328. doi:10.1016/j.intell.2009.04.005.

Murnane, R. J., & Willett, J. B. (2010). *Methods matter: Improving causal inference in educational and social science research*. Oxford: Oxford University Press.

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: Gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience, 27*, 435–453. doi:10.3233/RNN-2009-0496.

Noack, H., Lövdén, M., & Schmiedek, F. (2014). On the validity and generality of transfer effects in cognitive training research. *Psychological Research, 78*, 773–789. doi:10.1007/s00426-014-0564-6.

Redick, T. S. (2015). Working memory training and interpreting interactions in intelligence interventions. *Intelligence, 50*, 14–20. Retrieved from http://dx.doi.org/10.1016/j.intell.2015.01.014.

Rode, C., Robson, R., Purviance, A., Geary, D. C., & Mayr, U. (2014). Is working memory training effective? A study in a school setting. *PLoS One, 9*(8), e104796. doi:10.1371/journal.pone.0104796.

Schafer, J. L., & Graham, J. W. (2002). Missing data: Our view of the state of the art. *Psychological Methods, 7*, 147–177. doi:10.1037//1082-989X.7.2.147.

Schubert, T., & Strobach, T. (2012). Video game experience and optimized cognitive control skills—On false positives and false negatives: Reply to Boot and Simons (2012). *Acta Psychologica, 141*, 278–280. doi:10.1016/j.actpsy.2012.06.010.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for causal inference*. Boston, MA: Houghton Mifflin.

Shipstead, Z., Hicks, K. L., & Engle, R. W. (2012a). Cogmed working memory training: Does the evidence support the claims? *Journal of Applied Research in Memory and Cognition, 1*, 185–193. doi:10.1016/j.jarmac.2012.06.003.x.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012b). Is working memory training effective? *Psychological Bulletin, 138*(4), 628–654. doi:10.1037/a0027473.

Tidwell, J. W., Dougherty, M. R., Chrabaszcz, J. R., Thomas, R. P., & Mendoza, J. L. (2014). What counts as evidence for working memory training? Problems with correlated gains and dichotomization. *Psychonomic Bulletin & Review, 21*, 620–628. doi:10.3758/s13423-013-0560-7.

Vandenberg, R. J., & Lance, C. E. (2000). A review and synthesis of the measurement invariance literature: Suggestions, practices, and recommendations for organizational research. *Organizational Research Methods, 3*, 4–70. doi:10.1177/109442810031002.

von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: A review. *Psychological Research, 78*, 803–820. doi:10.1007/s00426-013-0524-6.

Theoretical Models of Training and Transfer Effects

Niels A. Taatgen

Introduction

Despite the large increase in interest and research on cognitive training, there is very little theory that can explain the effectiveness or lack thereof of cognitive training. There are two reasons for this. The first is the prevailing idea that cognitive training is similar to training muscles, and therefore requires little explanation. The second is that most detailed theories of cognitive training assume that what is learned in training is highly specific, which implies that general cognitive training is not really possible.

The muscle analogy of cognitive or "brain training" is quite pervasive. In particular, the term "brain training" suggests that it involves a physiological system that needs to become better or stronger (or has to be trained to prevent it from becoming weaker). It is also consistent with a tradition of viewing cognition as a collaboration between a set of cognitive functions or systems. For example, if we consider working memory as a system with a certain capacity, then the logical result of training working memory is the expansion of that capacity. Following the analogy leads to the idea that the various cognitive systems make up the muscles of the mind. However, there are several reasons why the muscle analogy may not be the most appropriate. First of all, the brain is not a muscle, nor anything like a muscle. Moreover, if brain training is like muscle training, why are the results so inconsistent? Reports of unsuccessful training are as common as successful reports, even without considering the publication bias that favors success over null results. Perhaps the successful training or testing regimens find some right combination, and the unsuccessful ones do not (see also Guye et al. this volume; Umanath et al. this volume).

N.A. Taatgen (✉)
University of Groningen, Groningen, The Netherlands
e-mail: n.a.taatgen@rug.nl

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_3

What makes humans such a successful species is not the strength of muscles, but the capability to fit in almost every niche in nature. In other words, humans are almost infinitely adaptable to different circumstances. Therefore, cognitive training can better be viewed as training and prioritizing of cognitive skills. For example, working memory training may not literally increase our capacity, but instead expand our cognitive strategies for maintaining information for relative short periods of time. This was definitely the case with subject SF in Chase and Ericsson's digit span training, where SF managed to expand his digit span from an average 7 to around 80 after 44 weeks of practice (Chase and Ericsson 1982). However, SF was not able to use this skill for anything else but digits. This brings us to the second reason why there is little theory about cognitive training, which is the strong belief that skills are seldom transferrable. The origin of this idea stems from Thorndike, who proposed the *identical elements* theory of transfer (Thorndike and Woodworth 1901). Only when the knowledge components are identical between two skills can there be transfer. Although Thorndike produced some evidence for lack of transfer between certain tasks, his methodology would not be considered as convincing when viewed in the context of today's standards. Singley and Anderson (1989) introduced a modern version of this theory where they specified the *production rule* as the element that has to be identical between tasks in order to produce transfer. Production rules are a form of knowledge representation that specifies how to achieve goals that take multiple actions. For example, to represent the skill of doing multi-column addition, production rules are needed that specify the different steps in performing that skill: focusing on a particular column, retrieving arithmetic facts from memory, writing down an answer underneath a column, remembering that there is a carry, and then handling that carry in the next column. To properly sequence these production rules, each of them has several conditions that need to be satisfied before they can be carried out. For example, having just finished a column is a condition for moving to the next column. The modern production rule assumes that it coordinates the exchange of information between more specialized cognitive modules (Anderson 2007). For example, a production rule may route information from visual perception to the memory retrieval system, route information from the memory system to the working memory, or an item from working memory to the motor system.

Typical procedural representations are quite specific for a particular task: the production rules for multi-column addition cannot be used in multi-column subtraction, despite some similarity between the two. This is why the Singley and Anderson theory, following Thorndike, predicts that transfer is a limited phenomenon. Empirical research followed this tradition with several studies that showed limited transfer through the use of analogy (e.g., Gick and Holyoak 1980). However, the existing methods are insufficient to explain result of many recent training studies. This means we need a new model paradigm to explain general effects of cognitive training.

The PRIMs Theory

If the effects of cognitive training can be explained by neither the muscle analogy nor the transfer of knowledge between tasks, what alternatives are left? Fortunately, there is another possible solution. The assumption of this solution is that when people learn *specific* cognitive skills, the by-product of the learning process consists of *general* cognitive skills. The general skills can be reused for different tasks without the need of explicit transfer between tasks. Moreover, the two tasks that share general skills can be quite different: they just share the same patterns of routing information through the cognitive system.

To implement a system along those lines, a more fine-grained representation than production rules is needed. Production rules typically carry out multiple smaller steps, only some of which are specific to the task. The PRIMs theory (Taatgen 2013b) breaks up production rules into these basic elements of information processing (PRIM = Primitive information processing element), and separates the task-specific from the task-general steps. What is called a rule in most production systems is an *operator* in PRIMs. Although it typically takes a single cycle to carry out a standard rule, an operator in PRIMs can take many more cycles, depending on the complexity of the operator, and the experience the system has with that operator. Operators are carried out by rules themselves which I will refer to as PRIM rules. PRIM rules operate at a smaller scale than standard production rules.

For example, in a model of multi-column addition, a production rule might take the two values in the column that has just been attended, and retrieve an addition fact from memory to calculate the sum. Such a rule would be useless in multi-column subtraction or multiplication, because the goal is different (and production rules a linked to the goal), and because a different kind of arithmetic fact has to be retrieved. However, part of the information exchange is the same: two elements of information from the visual system have to be transferred to the memory retrieval system, along with the information that we are trying to retrieve the sum of these two. We only do this when certain conditions are met: in this case the condition that we are attending a column with two numbers with nothing underneath it.

In PRIMs, this production rule would be represented by an operator that specifies the individual information processing steps. Before any learning has occurred, each of these steps is carried out by a separate PRIM rule (the production rule that initiates a memory retrieval in multi-column addition consists of six of these steps, and therefore needs six PRIM rules initially). However, once a particular sequence of two steps is used often enough, the learning mechanism called production compilation (Taatgen and Anderson 2002) combines them into a single new PRIM rule. This means that after some repetitions, the initial six PRIM rules have been combined into three composite PRIM rules that each carry out two basic steps. But this learning process continues when composite rules compile into larger composite rules that carry out four elementary steps, that then compile into a PRIM rule that carries out the whole operator at once. Figure 1 illustrates the learning sequence.

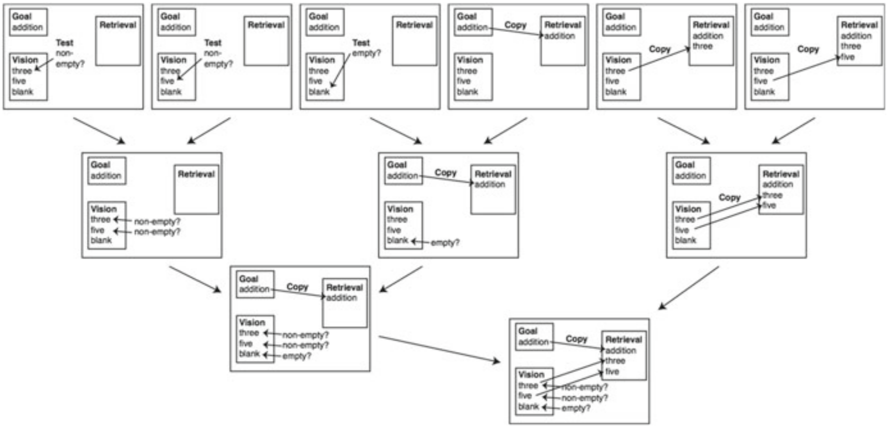

Fig. 1 Illustration of how a composite PRIM rule in multi-column addition (*bottom right box*) is learned from six elementary PRIM rules (*top row*). The three smaller boxes in each larger box represent the interface to the goal representation, to the long-term memory system ("retrieval"), and to the visual system. Rules carry out checks and transformations between these systems. Rules in the *top row* just carry out a single check or transformation, but after learning rules are composed that can do several of these at once

The PRIM rule at the bottom-right of Fig. 1 is a composite rule that carries out a relative complex pattern of information exchange, but is still independent of the particular task. This PRIM rule, or any of the other PRIM rules higher in the tree, can be reused for other tasks that need the same pattern of information exchange.

Multi-column addition consists of six operators that deal with retrieving arithmetic facts, writing down answers, moving from one column to the next, and dealing with carries. Multi-column multiplication needs eight operators to do the multiplication part, and another six to add up the results. The latter six are, of course, identical to multi-column addition. However, there is also partial overlap between the multiplication part and multi-column addition, because the procedure also deals with columns, carries, and the retrieval of arithmetic facts, but in a slightly different way.

Figure 2 shows a graphical representation of the two models. The six red nodes represent the six operators for multi-column addition. The bottom-right red node (retrieve addition fact) represents the operator we discussed in detail: it has three condition PRIMs (the string of three gray nodes), and three action PRIMs (the string of three white nodes). When we subsequently add the multi-column multiplication task, we only need an additional five operators instead of 14. We, of course, save the six operators that implement the multi-column addition subtask in multi-column multiplication. In addition, three more operators from multi-column addition can be directly reused for multi-column multiplication. In the figure these are the red nodes that are pointed to by an arrow from central multi-column multiplication node, for instance the "write answer" operator that writes the result of an arithmetic retrieval underneath a column. But even operators that are new can benefit from prior knowledge: the "retrieve multiplication fact" operator has the same PRIMs as the "retrieve addition fact" operator. This means that if the model has

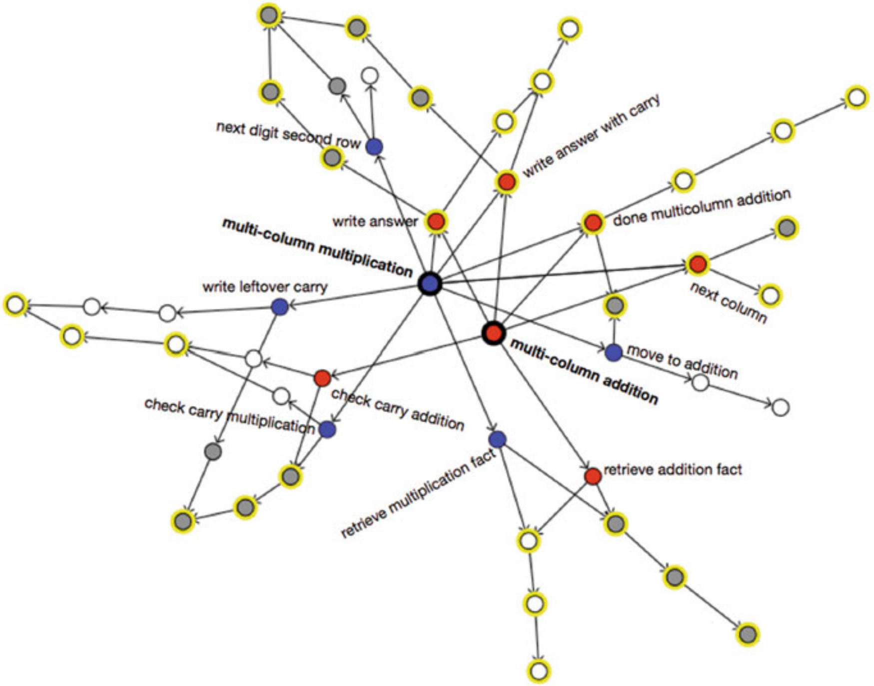

Fig. 2 Illustration of the operators for multi-column addition (*red nodes*), multi-column multiplication (*blue nodes*), and the primitive steps (PRIMs) connected to each of these operators (*white* and *gray*, *gray nodes* are conditions, while *white nodes* are actions). PRIMs that are used by both tasks, and therefore produce transfer, are indicated by a *yellow* halo. The two colored central nodes (multi-column multiplication and multi-column addition) are not operators but just nodes that connect to all the operators

learned the composite rule shown in Fig. 1, it can also use this rule to carry out the "retrieve multiplication fact" operator. The only reason we need a separate operator in this case is that one operator sets the value in the goal to "addition," while the other sets it to "multiplication." Partial overlap is also possible: the "check carry addition" and "check carry multiplication" operators differ by one PRIM, but share the others.

Figure 2 already shows that learning multi-column multiplication is much easier after first learning multi-column addition. Only five new operators have to be learned, but also the rules learned in multi-column addition can be reused. As a consequence, this model predicts that it is easier to learn multi-column multiplication after mastering multi-column addition. Moreover, it predicts that learning multi-column addition is harder than learning multi-column multiplication (assuming multi-column addition is learned first). But PRIMs does more than allow us to analyze the structure of the knowledge. Because it is based on the powerful ACT-R cognitive architecture (Anderson 2007), it can simulate how humans carry out these tasks, and make predictions about reaction times, errors, learning curves, and precise characteristics of transfer.

PRIMs Current Scope

The multi-column addition and multiplication example is a good illustration of the essence of PRIMs, but does not give us clear testable hypotheses. However, PRIMs has been successful in modeling several phenomena related to transfer and cognitive training.

Reuse of Skills in Text Editing

A first example is an experiment involving text editors that Singley and Anderson (1985) used to support their identical productions theory. In that experiment, subjects with no prior computer experience were trained on using three different text editors. Two of these were very similar in use (ED and EDT, both so-called line editors), while the third was different (Emacs, a screen-based editor). During the six-day experiment, subjects switch editors one, twice, or never at all, depending on which of the five conditions of the experiment they were. This design allowed Singley and Anderson to determine how much of the knowledge of one editor could be used for another editor. The amount of transfer between ED and EDT turned out to be very high, around 95 % of the knowledge for one editor could be used for the other editor. The Singley and Anderson model based on identical productions was able to capture this to a large extent (85 %). However, the experimental data also showed decent transfer between ED/EDT and Emacs, around 60 %, of which the identical productions model could only explain 33 %. The PRIMs model (Taatgen 2013b) that was based on roughly the same productions (translated into PRIMs operators) was able to fit the data much more precisely (predicting around 90 % transfer between ED and EDT, and 63 % between ED/EDT and Emacs). The reason is that PRIMs predicts transfer even if productions are not completely, but only partially identical. This meant that a large part of the knowledge gained by training on ED and EDT that was not directly applicable to Emacs could still be reused.

Training Skills in Brain Training

In the two examples that we have examined, arithmetic and text editing, the overlap between the tasks was quite substantial, and directly determined the amount of transfer between tasks. Another possibility is that the overlap between tasks is relatively small, but critical in determining a difference in performance. This is the case when there are multiple strategies to perform a task, and prior training leads to the selection of a better strategy than the one that would normally be preferred.

An example of this is a model of an experiment by Karbach and Kray (2009, see also Karbach and Kray this volume). In that experiment, subjects were trained on a particular variation of task switching. The training was effective in improving performance on several tasks, among which the Stroop task and a complex working memory task. All three of these tasks are considered to be tasks that measure *cognitive control*, but they are also tasks that have different strategies. We can broadly categorize the strategies as either *proactive* or *reactive* (Braver 2012). A reactive strategy means that behavior is driven by the stimuli in the experiment. For example, in the Stroop task a reactive strategy involves waiting for the stimulus, attending it, and then naming the color of the letters. During the attending step the identity of the word has the opportunity to interfere with the color of the letters, producing the Stroop effect. However, a proactive strategy can reduce this effect. Proper preparation before the stimulus appears can change the "default" attention step to be replaced by an attending step that focuses on just the color of the letters, strongly reducing the interference. Proactive strategies are therefore characterized by task-related processing or preparation that is not directly cued by the stimuli. Proactive strategies tend to be more complex than reactive strategies in the sense they need more operators when modeled, and also more vulnerable to mental distraction, because there is no external cue that triggers the proactive step.

In most task-switching paradigms subjects also have a choice to proactively prepare for the next stimulus, or to wait for the stimulus and then decide what to do (De Jong 1995). However, in the Karbach and Kray experiment subjects were forced to be proactive, because there was no external cue from which the current task could be deduced. As a consequence, whether by accident or design, task switching effectively trained a proactive strategy. In the PRIMs model, the proactive strategy consisted of an operator that initiated task preparation before the stimulus appeared (Taatgen 2013b). A subsequent operator would react to this preparation after the stimulus appeared. In the case of the Stroop task, the subsequent operator would focus attention on the color of the stimulus, overruling the default operator that would attend all attributes of the stimulus. In the case task switching, the preparing operator would adjust the task goals before the stimulus, after which the subsequent operator immediately carry out the task goal. Training on task switching was effective, because the proactive operators were trained and therefore became more efficient to use. After training the choice for a proactive strategy on the Stroop task became more attractive, because that strategy could use the same operators.

The model can also explain the improvement on the complex working memory task. In complex working memory tasks, subjects typically have to remember a sequence of items, but between the presentation of these items they have to perform another task. In order to be successful on the memory part of the task, it is necessary to perform maintenance rehearsal, but due to the continuous nature of the task as a whole there is no natural moment to do this. Subjects therefore need to force themselves to do rehearsal at moments that new stimuli also demand their attention. Therefore, in a complex working memory task, a reactive strategy is to not rehearse at all, or only in brief moments that there is no stimulus, whereas a proactive strategy tries to insert a rehearsal even in the presence of stimuli that demand a response.

If the model of training in the Karbach and Kray experiment is correct, this has repercussions on the effectiveness of brain training. It predicts that brain training is only effective if the cognitive skill that is trained is useful for the tasks that the subjects are tested on, and also effective if the skill in question isn't one that subjects would normally have preferred anyway.

Diminishing Return in Expertise

If we reject the notion of the muscle analogy to cognitive training, we should also question cognitive training regimens in which the same task is repeated very often, even if that task is gradually increased in difficulty. It is generally assumed that cognitive training adheres to the laws of diminishing returns. For example, there is some evidence that if children learn chess, this has a positive impact on cognitive performance in other areas. However, a chess grandmaster probably has much less benefit of the more advanced strategies in chess (Doll and Mayr 1987).

A study by Frensch (1991) demonstrated this in a study in which subjects repeatedly solved a set of six equations. Some subjects received the training in a blocked paradigm, which means they were trained on equation 1 a number of times, then equation 2 a number of times, etc. A second group would have to solve the equations in a fixed order: equation 1 first, then equation 2, equation 3, etc., and after the last equation back to equation 1. The third group would have to solve the equations in random order. After a certain amount of training in one of the three conditions, all conditions switched to the fixed order version of the task. Frensch found that if the switch took place after a modest amount of training (25 × 6 equations), subjects all performed equally well after the switch to the fixed order. However, if the switch appeared after a large amount of training (75 × 6 equations), the pattern was different: subjects who were trained in the fixed condition now performed much better than those trained in the other conditions. In particular, in the blocked condition performance after short training was identical to performance after long training. In other words, the training between 25 and 75 blocks was only helpful for solving the equations in a particular order.

A PRIMs model of this task (Taatgen 2013a) shows a large overlap in operators that are needed to solve the equations. They generally consist of operators that substitute variables by values, and operators that do basic arithmetic. Because of this overlap, the model will rapidly become more efficient at solving the particular equations. The difference between the conditions is mainly in terms of task control. In the fixed order condition, control mainly involves anticipating and moving to the next equation. This operation is less frequent than the operators that solve equations, and is therefore learned more slowly. Early transfer is therefore characterized by transfer in solving the equations. Late transfer is characterized by control, which is different for each of the conditions.

Apart from the specific prediction the model makes for this experiment, generally longer training on the same task leads to rules that are able to handle longer chains of PRIMs. The probability that such a long, specialized chain can be transferred to another task becomes smaller (see also Newell and Rosenbloom 1981, for a similar argument).

Stages or Phases in Development

There is an ongoing debate in developmental psychology on the status of stages or phases in development (Piaget 1952). Although few now believe children progress from one stage to another across the board, a process that could explain a sudden progression in different areas of development is the acquisition of general cognitive skills that are useful for many different things. For example, van Rijn et al. (2002) built a cognitive model that described the progression through various stages of the balance beam task. In that task, children have to determine which side of a balance goes down, taking into account both weight and distance from the middle of the balance. In order to reach the higher stages of performance, children have to be able to integrate the two dimensions (weight and distance) in this task. Van Rijn et al. needed to assume in their model that this multidimensional integration skill was one that the child discovered elsewhere, and could then apply it in the balance beam task.

To explore this idea, Gittelson and Taatgen (2014) reimplemented three of the stages of the van Rijn model in PRIMs, along with three models of decision making of increasing complexity that follow the heuristics of Gigerenzer and Goldstein (1996): the recognition heuristic, the take-the-best-heuristic, and the weighed averages heuristic. These heuristics are used to make choices between two options, for example which of two cities is larger. The take-the-best heuristic prescribes that you take the most important attribute of each of the cities (e.g., does the city have an airport), and base your decision on that attribute. If you cannot make a choice on the basis of the most important attribute, you move to the second most important attribute (e.g., does the city have a premier league soccer team). This heuristic is similar to stage 2 in the balance beam task, where children first look at weight, and only if the weights are equal pay attention to distance.

The models showed considerable transfer, not just *vertical transfer*, in the sense that it is easier to learn the second stage of the balance beam task once the first stage is mastered, but also *horizontal transfer*, in the sense that mastery of the take-the-best heuristic makes it easier to learn the second stage of the balance beam task. This means that discovery of the take-the-best heuristic also facilitates moving from stage 1 to stage 2 in the balance beam task, and maybe other tasks as well. Therefore discovery of a “stage 2” strategy may trigger advances in several different tasks, giving the impression of an across-the-board stagewise developmental transition.

Conclusions

The central idea of PRIMs is that general cognitive strategies are learned as a by-product of task-specific learning. This principle can explain classical transfer effects, the effects of brain training, the limitations of expertise, and potentially aspects of cognitive development. PRIMs software, including the models described in this chapter, is available on: http://www.ai.rug.nl/~niels/actransfer.html.

Acknowledgements This research was supported by European Research Council Starting Grant MULTITASK 283597.

References

Anderson, J. R. (2007). *How can the human mind occur in the physical universe?* New York: Oxford University Press.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. doi:10.1016/j.tics.2011.12.010.

Chase, W. G., & Ericsson, K. A. (1982). Skill and working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 1–58). New York: Academic.

De Jong, R. (1995). The role of preparation in overlapping-task performance. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 48*(1), 2–25. doi:10.1080/14640749508401372.

Doll, J., & Mayr, U. (1987). Intelligenz und Schachleistung—eine Untersuchung an Schachexperten. [Intelligence and success in chess playing: An examination of chess experts]. *Psychologische Beitrage, 29*(2–3), 270–289.

Frensch, P. A. (1991). Transfer of composed knowledge in a multistep serial task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(5), 997–1016. doi:10.1037/0278-7393.17.5.997.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306–355. doi:10.1016/0010-0285(80)90013-4.

Gigerenzer, G., & Goldstein, D. G. (1996). Reasoning the fast and frugal way: Models of bounded rationality. *Psychological Review, 103*(4), 650–669. doi:10.1037/0033-295X.103.4.650.

Gittelson, L., & Taatgen, N. A. (2014). Transferring primitive elements of skill within and between tasks. In P. Bello, M. Guarini, M. McShane, & B. Scassellati (Eds.), *Proceedings of the 36th Annual Meeting of the Cognitive Science Society* (pp. 529–534). Quebec City, Canada.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978–990. doi:10.1111/j.1467-7687.2009.00846.x.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1–56). Hillsdale, NJ: Erlbaum.

Piaget, J. (1952). *The origins of intelligence in children*. New York: International University Press.

Singley, M. K., & Anderson, J. R. (1985). The transfer of text-editing skill. *Journal of Man–Machine Studies, 22*(4), 403–423. doi:10.1016/S0020-7373(85)800447-X.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*. Cambridge, MA: Harvard University Press.

Taatgen, N. A. (2013a). The nature and transfer of cognitive skills. *Psychological Review, 120*(3), 439–471. doi:10.1037/a0033138.

Taatgen, N. A. (2013a). Diminishing return in transfer: A PRIM model of the Frensch (1991) arithmetic experiment. In *Proceedings of the International Conference on Cognitive Modeling* (pp. 29–34). Ottawa, Canada: Carleton University.

Taatgen, N. A., & Anderson, J. R. (2002). Why do children learn to say "broke"? A model of learning the past tense without feedback. *Cognition, 86*(2), 123–155. doi:10.1016/S0010-0277(02)00176-2.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247–261.

van Rijn, H., van Someren, M., & van der Maas, H. (2002). Modeling developmental transitions on the balance scale task. *Cognitive Science, 107*, 1–31.

Part II
Plasticity in Different Age Groups

Childhood and Adolescence

M. Rosario Rueda, Lina M. Cómbita, and Joan P. Pozuelos

Introduction: Promoting Cognitive Skills During Development

Fostering the mental and emotional potential of people is an important endeavor of developmental psychologists and other professionals in the field of Human Development and Education. There is great consensus on the idea that a society is in the tracks toward economic and social flourishing when it can provide the means to make the most of cognitive abilities and emotional well-being of its members (Beddington et al. 2008).

Throughout generations of researchers, the question of whether experience and/or environmental factors influence children's cognitive capacities has been fundamental in the study of human development. This question brought about an intense debate on the extent to which the development of cognitive capacities is determined by genes or else depends on experience. Precisely quantifying the contribution of these two factors to development is very difficult. However, research suggests that nurture matters and that both genetic and environmental factors impact the development of brain and cognition. Aware of the fact that there is a large scope for improving cognitive abilities by means of experience, there have been an increasing number of studies in the last decade aiming at examining the impact of training programs in children's cognitive capacities. In the light of the substantial evidence provided by this research, the query of whether it is possible to enhance children's cognitive and emotional capacities becomes a question of what are the most beneficial methods, as well as a question of what are the periods of development in which intervention may be more effective.

In this chapter, we first discuss about the importance of early interventions in relation to possible developmental differences in brain plasticity. Next, we present an overview of the multiple studies that have been conducted in the past years to

---

M.R. Rueda (✉) • L.M. Cómbita • J.P. Pozuelos
Department of Experimental Psychology, Center for Research on Mind, Brain, and Behavior (CIMCYC), Universidad de Granada, Granada, Spain
e-mail: rorueda@ugr.es; lmcombita@ugr.es; jpoll@ugr.es

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_4

examine training-related gains in diverse cognitive domains through randomized controlled trials. In the last section of the chapter, we discuss the relevance of this line of research for education and clinical practice.

Plasticity During Development

Cognitive training thrives on the lure of the plastic nature of the brain. It is well known that the brain changes in response to experience or environmental stimulation. Many studies have shown the impact of family/school environment on a variety of cognitive skills, including executive attention, working memory, and intelligence, as well as the function and structure of the brain networks supporting them (Hackman and Farah 2009). All these skills are crucial to school learning, and their vulnerability to poverty very likely explains the largely documented robust association between low family socioeconomic status and children's poor academic outcomes. Yet, the same plastic nature of the cognitive system that enables negative experience to undermine cognitive skills also opens a window to beneficial effects of positive environment and developmental intervention. A large bulk of evidence shows that a good number of factors, from lifestyle (e.g., exercise, sleep, exposure to nature) to intervention and education, causes physiological, structural, and functional changes in the brain, which promote the development and enhancement of cognitive processes (Beddington et al. 2008).

In humans, the development of brain structures underlying superior cognitive abilities shows a developmental trajectory that extends during the first and a large proportion of the second decades of life. Developmental trajectories are not equal for brain regions supporting different cognitive skills. While structures that support more basic perceptual and sensory processes develop earlier in life, structures that support more complex processes (e.g., language, executive functions, social cognition) continue developing during late childhood and adolescence (Shaw et al. 2008). Due to this principle of brain development, the potential for brain plasticity varies over development and across brain regions. Sensitive periods of development (i.e., times during which a neural system is maximally sensitive to environmental influences) have been long believed to run in the first and second years of life. Although this might be the case for sensory systems such as vision, hearing, and aspects of language, sensitive periods for higher cognitive functions that rely on prefrontal regions are thought to stretch late into childhood and adolescence (Rice and Barone 2000). For these reasons, a child's brain is believed to be more plastic than an adult's; however, it is not the case that inputs to the system after the end of sensitive periods can no longer influence cognition. There are examples in different domains of a high degree of plasticity outside the sensitive period. In fact, some authors consider that the protracted development of the neural system constitutes a sustained sensitive period, where environmental influences support the fine-tuning and shaping of cortical circuits that underlie higher-order cognitive processes (Johnson 2011).

Training of Diverse Cognitive Skills in Childhood and Adolescence

A large bulk of studies have been carried out in the past decade in order to examine the potential benefits of cognitive training programs on the development of cognitive skills and the brain mechanisms that support them. Although studies often differ in methods, length, and intensity of intervention, most of them have targeted cognitive processes that fall under the umbrella of executive functions (EFs), namely, working memory (WM), inhibitory control, executive attention, and cognitive flexibility (see Karbach and Kray this volume). The development of EFs enables the top-down coordination and regulation of thoughts, behaviors, and emotions necessary to flexibly adapt to the demands of a changing environment. EFs have been particularly stressed in training research because of the role they play on several aspects of children's and adolescents' development such as social adjustment, academic competence, and mental health (Checa et al. 2008; Rothbart and Posner 2006).

Generally, cognitive training refers to programs designed to improve the efficiency of cognitive and brain mechanisms through practice and/or intentional instruction. Most training studies have taken a process-based approach, which consists on training specific cognitive processes by means of practicing with tasks that entail such processes. A different training strategy consists on providing instructions to develop metacognitive knowledge about task relevant procedures, an approach that remind of the Vygotskyan concept of scaffolding, or providing information about particular strategies that may enhance task performance (e.g., using visuospatial cues to improve memory; Karbach and Unger 2014).

Mostly the effects of cognitive training are studied on the performance of tasks that tap the same process or processes targeted with the intervention (near transfer), although often effects are also measured in the performance of tasks that engage processes different from, albeit related to, those being trained (far transfer). For instance, given that EFs are central to the development of higher-order executive functions such as reasoning, problem solving, and planning, several studies have addressed the generalization of EF training to other functions such as fluid intelligence, schooling skills, or the improvement of symptoms in the case of children with attention-deficit/hyperactivity disorder (ADHD).

In the following sections, we provide an overview of the empirical evidence derived from studies that have examined the impact of cognitive training in infants, children, and adolescents in the past decade. We mostly cover studies using a process-based approach, a large amount of which used computer-based training programs. Also, we describe other studies that have used non-computerized programs, some of which used scaffolding or a different type of coaching (e.g., mindfulness). The evidence reviewed covers behavioral and neuroimaging data of the impact of training programs on three main domains of the EFs in typically developing children and clinical populations.

Working Memory

Working memory is perhaps the EF domain with the largest amount of training studies. Most studies involve the use of computer-based programs aiming at practicing the ability to monitor, update, and manipulate information in memory for short periods of time by performing n-back or memory span tasks in increased levels of difficulty. In a typical n-back exercise, children are presented with sequences of stimuli, and their task is to report whenever the current stimulus is similar to the one presented *n* items back in some particular dimension (e.g., location, color, sound, etc.; Jaeggi et al. 2011). Memory span exercises require children to retain series of visuospatial or verbal stimuli in memory and repeat them after a brief delay either in the same or the reversed order of presentation. Using this type of exercises for training, several studies have demonstrated enhancements of WM capacities in typically developing children (Alloway et al. 2013) as well as in children and adolescents diagnosed with attention-deficit/hyperactivity disorder (ADHD; Holmes et al. 2010; Stevens et al. 2015).

Besides near-transfer effects, there is evidence that WM training also translates into significant benefits in different domains of children's lives. With children and adolescents (7–15-year-olds) diagnosed with ADHD, Klingberg and colleagues have shown significant improvements on measures of nonverbal reasoning ability and inhibitory control in trained children compared to an active control group (i.e., children who only performed the initial levels of the training program; Klingberg et al. 2002, 2005). Using the same or similar training protocol, parents of children who received the treatment reported amelioration on the severity of inattentive and impulsivity/hyperactive symptoms exhibited by their children (Klingberg et al. 2005; Stevens et al. 2015).

Additionally, a few studies have tested the generalization of WM training effects into measures of verbal competence and reading performance in typically developing children. In one of such studies, Alloway et al. (2013) reported higher scores on fluid intelligence as well as a significant improvement on measures of verbal competence and spelling following 32 sessions of WM training. Importantly, WM gains and transfer to verbal competence and spelling were still maintained in a follow-up assessment carried out 8 months after the intervention. Transfer of WM training to reading performance has also been reported with shorter interventions (Karbach et al. 2015; Loosli et al. 2012), suggesting that the length of the program may not determine the generalization of WM training to children's reading competence.

Some studies have also explored the neural mechanisms that underlie training-related improvements of WM in children and adolescents. Jolles et al. (2012) found that, after 6 weeks of WM training, children showed significant pre- to post-training increases of activation in frontoparietal structures. Likewise, in a different study conducted with adolescents diagnosed with ADHD, it was found that the magnitude of the pre- to post-training increase of frontoparietal activation predicted participants' gains in WM following training. More importantly, the observed changes in neural activation were distinctly correlated with the reduction of inattention and hyperactive/impulsive symptoms after training (Stevens et al. 2015).

Executive Attention and Inhibitory Control

Because of its involvement in perceptual processing and behavioral regulation, attention is central to most of our activities in daily life. Out of the broad concept of attention, executive attention refers to goal-directed behavior and action regulation and involves processes such as inhibitory control, conflict resolution, and attentional flexibility. Given that executive attention strongly develops during the first years of life (Rueda 2014), many training studies have focused on the behavioral and neural effects of cognitive interventions during the preschool years.

Although the number of studies targeting executive attention processes is still small, the evidence that has been gathered in the past decade suggests that these interventions translate into near- (Thorell et al. 2008) and far-transfer effects, particularly to measures of fluid intelligence (Liu et al. 2015; Rueda et al. 2012). In order to assess the influence of training in the plasticity of brain dynamics, some of these studies have also recorded brain activity measures using electroencephalography (EEG). Results show that training induces enhanced amplitude of attention-related ERP components (Liu et al. 2015), as well as a reduction in latency of brain responses while performing executive attention tasks (Rueda et al. 2005, 2012). Importantly, these effects are still observed two months after intervention without further training (Rueda et al. 2012). Additional research is needed to examine to what extent pre- to post-training changes in the patterns of brain function are related to the generalization of training effects to other cognitive domains. Also, research covering different age groups is needed in order to characterize the effect of training across development.

Cognitive Flexibility

Cognitive flexibility is the ability to change the course of action to adapt effectively to the changing demands of a given task or situation. This skill greatly relies on the capacity to update information in WM and implement attentional and behavioral control mechanisms. In fact, developmental studies have shown that among the executive domains, cognitive flexibility emerges later and exhibits a more protracted development, extending to late adolescence (Cepeda et al. 2001).

Most of the training studies on cognitive flexibility have been carried out with groups of school-aged children, usually starting at the age of 7 years, using a variety of exercises based on the classical task-switching paradigm. Switching tasks often involve responding to stimuli according to particular rules, which can change from one trial to the next. For example, series of numbers are presented, and the participant is asked to indicate whether the number is odd or even (task A) if printed in red ink (cue for task A) or indicate whether the number is larger or smaller than 5 (task B) if printed in blue ink (cue for task B). The task requires flexibly switching between sets of rules and adjusting response-mapping representations accordingly.

Although the number of studies is still small, evidence indicates that after switching training, children and adolescents show improvements in cognitive flexibility measures, as well as far-transfer effects to other cognitive domains. For instance, Karbach and Kray (2009) reported that task-switching training results in significant transfer to measures of response inhibition, verbal and spatial WM, and fluid intelligence. Similar results have also been reported in studies that trained children diagnosed with ADHD. Together with improvements on cognitive flexibility, children trained in task switching showed better performance on measures of inhibitory control and verbal WM (Kray et al. 2012), as well as faster choice reaction times and a tendency toward faster responses when performing an updating task (Zinke et al. 2012), compared to children who received different training protocols.

Despite the small number of studies that have been conducted, the evidence presented here suggests that cognitive flexibility can be enhanced during development and that such beneficial effects translate into the improvement of other cognitive functions. However, given the lack of studies that investigate changes of brain function following switching-based interventions, information necessary to characterize the neural mechanisms that underlie the observed behavioral effects is lacking.

Multi-domain Training

In view of the overlapping neuroanatomy of executive functions in the prefrontal cortex, a number of studies have approached cognitive training implementing a multi-domain strategy. For example, Wass et al. (2011) studied the influence of a multi-domain training protocol based on a number of gazed-contingent exercises that aimed to train executive attention (focused/selective attention, interference resolution, visual search) as well as WM and cognitive flexibility in infants. They found that infants significantly improved their performance on measures of cognitive control, sustained attention, and attentional control following training, although no gains were found in WM.

Also, given that children diagnosed with ADHD exhibit cognitive and behavioral symptoms related to the different EF domains, several studies have implemented training protocols that target two or more executive-related processes. In one of the studies, near-transfer effects were limited to measures of visuospatial WM and inhibitory control, while no significant differences were observed for measures of verbal WM and cognitive flexibility (Dovis et al. 2015). Furthermore, training also led to the amelioration of the frequency and severity of the ADHD symptoms (Johnstone et al. 2012). Transfer between EF tasks in multi-domain training is expected given the overlapping neuroanatomy, yet further research is needed for a detailed understanding of the neural dynamics underlying training benefits.

Non-computerized Training Programs

So far, we have described studies using process-based training interventions mostly based on computerized exercises designed to target specific cognitive functions. However, other studies have examined the effects of interventions implemented in the classroom, either as incorporated to the school curricula or as extracurricular activities performed in the school context.

An example of school curricula that incorporates exercises aimed at increasing EFs is the so-called *Tools of the Mind* program (Bodrova and Leong 2007). This is a program based on Vygotsky's insights into development of high cognitive functions, emphasizing training of EFs through guided social interactions in the classroom. Diamond and colleagues (2007) were able to evaluate the impact of the *Tools* program in children's EF skills during the second year of preschool, in comparison to a different curriculum implemented by the school district, which had the same academic content but did not emphasize EFs. Data revealed better performance of children in the *Tools* program in executive control tasks, an effect that was bigger in task conditions with higher executive demands.

Hermida and colleagues (2015) took a somewhat different approach in a recent study. They trained teachers to include activities to promote executive functions (WM, attention, inhibitory control, and planning) in the classroom and tested both near- and far-transfer effects of intervention to behavioral tests of EF and academic achievement, respectively. Results failed to show significant differences in EF performance between children in the intervention and control groups; however, they found significant differences in four of the six academic achievement areas evaluated: language and mathematics, autonomy, and socialization with peers. Similarly, Tominey and McClelland (2011) conducted a randomized trial with a group of 65 preschool children. Half of the children were assigned to participate in 16 playground sessions in which children played different games designed to promote WM, attention, and inhibitory control. They found benefits of the intervention in letter-word identification for all children in the treatment group, but gains in self-regulation skills were only observed for the group of children with lower initial scores in those skills.

A different approach to promoting self-regulatory skills at school that is generating promising results is mindfulness practice. Mindfulness is a contemplative exercise that aims at improving the ability to have a nonjudgmental awareness that arises by paying attention to the present moment (Malinowski 2013). In a randomized control study with 7–9-year-old children, Flook and colleagues (2010) examined the effects of mindful awareness practice on parent- and teacher-reported measures of EF. They reported gains in behavioral regulation, metacognition, and executive control scores after mindfulness training for children who were less regulated before intervention. Improvements were found with both teacher- and parent-reported measures, suggesting that benefits of practice in children's regulation generalized across different settings.

Overall, these interventions show promising results and point to the importance of incorporating interventions to promote cognitive and self-regulation skills into school curricula (see Alloway et al. this volume). Importantly, stronger effects of interventions are consistently found on children with greater difficulties. This suggests that there exist individual differences in windows of improvement. Knowing whether upper boundaries of these improvement windows depend on the developmental stage of the individual remains a future research question.

Implications of Training for the School and Clinic

Education

Children's academic learning and school adjustment are supported by cognitive abilities such as attention, memory, and intelligence. We know that attention and self-regulation skills are key to school readiness because of their power to predict later achievement in school (Duncan et al. 2007) and many other life outcomes (Moffitt et al. 2011). Age (developmental stage) and constitution (temperament and genes) are two important sources of inter-individual variability that are to be taken into account to optimize learning and adjustment in schools. Abundant evidence presents attention as an integral component in the academic success of children. Variability in attentiveness and self-regulation accounts for differences in learning and socio-emotional competencies displayed in the classroom (Checa et al. 2008). Moreover, there is evidence showing that neural markers of executive attention contribute to predict children's grades in mathematics (Checa and Rueda 2011). This evidence speaks up for the importance of promoting children's cognitive capacities as part of the educational curricula.

The usefulness of training tools for education will increase to the extent that their development is evidence-based and guided by scientific principles. Hence, the design of training programs must align with known processes of children's learning and cognitive development. Literature in psychological science suggests that children learn best when they are cognitively active and engaged, when learning experiences are meaningful and socially interactive, and when learning is guided by a specific goal (Hirsh-Pasek et al. 2015). With the foundation of these learning pillars, psychologists and educators can take a proactive approach to the development and evaluation of intervention tools aimed to enhance children's odds to successful learning and socio-emotional outcomes.

Prevention and Intervention

The understanding of pathophysiological mechanisms of developmental diseases offers a way through which a particular pathology may be changed. The development of efficient treatments is greatly facilitated by knowing the pathological mechanisms of diseases, because once pathological mechanisms are identified, they become putative targets of intervention (see Belleville et al. this volume).

Comorbidities are common in developmental disorders. For instance, deficits of executive attention appear to underlie both autism spectrum disorder (ASD) and ADHD (van der Meer et al. 2012). In this context, process-based training may constitute a suitable method for disease prevention and treatment. Early intervention to train executive attention in children at risk for developing these disorders may act as a general positive or protective factor such that children with strong executive attention skills have better developmental outcomes. This approach has already proven to be beneficial for children with ADHD. As discussed earlier, several studies have shown that working memory and executive control training in children with ADHD improve performance and increase neural efficiency in relevant brain circuits, although with limited transfer to behavioral symptoms and academic outcomes, although additional studies with more extended interventions are needed.

In addition, studying the impact of training on the targeted function at the brain and behavior level, and the subsequent relationship of the training effect to the clinical outcome, facilitates an understanding of mechanisms of action of particular interventions. Importantly, effectiveness of treatment has to be tested with randomized trials including treatment and placebo groups. In such studies, interventions can be considered efficient to the extent that they revert or palliate pathological mechanisms. In turn, information on individual differences in effectiveness has the potential to help building more putatively more potent, personalized interventions.

Conclusions and Future Research

One of the biggest challenges of modern societies is to find methods to foster children's cognitive and emotional skills. In an increasingly technological world, nurturing mental wealth is a major way to prosper both economically and socially. To accomplish this objective, psychologists and educators must work together to provide individuals with tools that can optimize cognitive skills and prevent or palliate the development of psychopathologies.

Future research will be key for identifying risk factors and behavioral, cognitive, and neural markers of learning difficulties and neurodevelopmental disorders, as well as to studying the factors (e.g., genetic, temperamental, etc.) that determine the effectiveness of interventions designed to fight these harmful conditions. Crucially, multidisciplinary longitudinal studies are needed in order to deepen our understanding of the complex processes supporting typical and atypical development and use this knowledge to improve developmental interventions.

Acknowledgments Work of authors is supported by a grant from the Spanish Ministry of Economy and Competitiveness (rf. PSI2014-55833-P) awarded to the first author.

References

Alloway, T. P., Bibile, V., & Lau, G. (2013). Computerized working memory training: Can it lead to gains in cognitive skills in students? *Computers in Human Behavior, 29*(3), 632–638. doi:10.1016/j.chb.2012.10.023.

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., et al. (2008). The mental wealth of nations. *Nature, 455*, 1057–1060. doi:10.1038/4551057a.

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind*. Ohio, NJ: Pearson.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology, 37*(5), 715–730. doi:10.1037/0012-1649.37.5.715.

Checa, P., Rodríguez-Bailón, R., & Rueda, M. R. (2008). Neurocognitive and temperamental systems of self-regulation and early adolescents' social and academic outcomes. *Mind, Brain, and Education, 2*(4), 177–187. doi:10.1111/j.1751-228X.2008.00052.x.

Checa, P., & Rueda, M. R. (2011). Behavioral and brain measures of executive attention and school competence in late childhood. *Developmental Neuropsychology, 36*(8), 1018–1032. doi:10.1080/87565641.2011.591857.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science (New York, NY), 318*(5855), 1387–1388. doi:10.1126/science.1151148.

Dovis, S., Van der Oord, S., Wiers, R. W., & Prins, P. J. M. (2015). Improving executive functioning in children with ADHD: Training multiple executive functions within the context of a computer game. A randomized double-blind placebo controlled trial. *PLOS One, 10*(4), e0121651. doi:10.1371/journal.pone.0121651.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., et al. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428–1446. doi:10.1037/0012-1649.43.6.1428.

Flook, L., Smalley, S. L., Kitil, M. J., Galla, B. M., Kaiser-Greendland, S., Locke, J., Ishijima, E., & Kasari, C. (2010). Effects of mindful awareness practices on executive functions in elementary school children. *Journal of Applied School Psychology, 26,* 70–95. doi:10.1080/15377900903379125.

Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences, 13*(2), 65–73. doi:10.1016/j.tics.2008.11.003.

Hermida, M. J., Segretin, M. S., Prats, L. M., Fracchia, C. S., Colombo, J. A., & Lipina, S. J. (2015). Cognitive neuroscience, developmental psychology, and education: Interdisciplinary development of an intervention for low socioeconomic status kindergarten children. *Trends in Neuroscience and Education, 4*(1–2), 15–25.

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in "educational" apps: Lessons from the science of learning. *Psychological Science in the Public Interest, 16*(1), 3–34. doi:10.1177/1529100615569721.

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology, 24*(6), 827–836. doi:10.1002/acp.1589.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America, 108*(25), 10081–10086. doi:10.1073/pnas.1103228108.

Johnson, M. H. (2011). Interactive specialization: A domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience, 1*(1), 7–21. doi:10.1016/j.dcn.2010.07.003.

Johnstone, S. J., Roodenrys, S., Blackman, R., Johnston, E., Loveday, K., Mantz, S., et al. (2012). Neurocognitive training for children with and without AD/HD. *Attention Deficit and Hyperactivity Disorders, 4*(1), 11–23. doi:10.1007/s12402-011-0069-8.

Jolles, D. D., van Buchem, M. A., Rombouts, S. A. R. B., & Crone, E. A. (2012). Practice effects in the developing brain: A pilot study. *Developmental Cognitive Neuroscience, 2*(1), 180–191. doi:10.1016/j.dcn.2011.09.001.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978–990. doi:10.1111/j.1467-7687.2009.00846.x.

Karbach, J., Strobach, T., & Schubert, T. (2015). Adaptive working-memory training benefits reading, but not mathematics in middle childhood. *Child Neuropsychology, 21*(3), 285–301. doi:10.1080/09297049.2014.899336.

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390. doi:10.3389/fpsyg.2014.00390.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., et al. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177–186. doi:10.1097/00004583-200502000-00010.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781–791. doi:10.1076/jcen.24.6.781.8395.

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can task-switching training enhance executive control functioning in children with attention deficit/-hyperactivity disorder? *Frontiers in Human Neuroscience, 5*, 1–9. doi:10.3389/fnhum.2011.00180.

Liu, Q., Zhu, X., Ziegler, A., & Shi, J. (2015). The effects of inhibitory control training for preschoolers on reasoning ability and neural activity. *Scientific Reports, 5*, 14200. doi:10.1038/srep14200.

Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology, 18*(1), 62–78. doi:10.1080/09297049.2011.575772.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience, 7*, 8. doi:10.3389/fnins.2013.00008.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences, 108*(7), 2693–2698. doi:10.1073/pnas.1010076108.

Rice, D., & Barone, S. (2000). Critical periods of vulnerability for the developing nervous system: Evidence from humans and animal models. *Environmental Health Perspectives, 108*(3), 511–533. Retrieved August 27, 2015, from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1637807&tool=pmcentrez&rendertype=abstract.

Rothbart, M. K., & Posner, M. I. (2006). Temperament, attention, and developmental psychopathology. In D. Cicchetti & D. Cohen (Eds.), *Developmental psychopathology* (Developmental neuroscience 2nd ed., Vol. 2, pp. 465–501). Hoboken, NJ: Wiley.

Rueda, M. R. (2014). Development of attention. *The Oxford handbook of cognitive neuroscience* (Vol. 1, pp. 296–318). Oxford: Oxford University Press. doi:10.1093/oxfordhb/9780199988693.013.0015.

Rueda, M. R., Checa, P., & Cómbita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience, 2*(1), 192–S204. doi:10.1016/j.dcn.2011.09.004.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America, 102*(41), 14931–14936. doi:10.1073/pnas.0506897102.

Shaw, P., Kabani, N. J., Lerch, J. P., Eckstrand, K., Lenroot, R., Gogtay, N., et al. (2008). Neurodevelopmental trajectories of the human cerebral cortex. *Journal of Neuroscience, 28*(14), 3586–3594. doi:10.1523/JNEUROSCI.5309-07.2008.

Stevens, M. C., Gaynor, A., Bessette, K. L., & Pearlson, G. D. (2016). A preliminary study of the effects of working memory training on brain function. *Brain Imaging and Behavior, 10*(2), 387–407. doi:10.1007/s11682-015-9416-2.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2008). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106–113. doi:10.1111/j.1467-7687.2008.00745.x.

Tominey, S., & McClelland, M. M. (2011). Red light, purple light: Findings from a randomized trial using circle time games to improve behavioral self-regulation in preschool. *Early Education Development, 22*(3), 489–519. doi:10.1080/10409289.2011.574258.

van der Meer, J. M. J., Oerlemans, A. M., van Steijn, D. J., Lappenschaar, M. G. A., de Sonneville, L. M. J., & Buitelaar, J. K., et al. (2012). Are autism spectrum disorder and attention-deficit/hyperactivity disorder different manifestations of one overarching disorder? Cognitive and symptom evidence from a clinical and population-based sample. *Journal of the American Academy of Child and Adolescent Psychiatry, 51*(11), 1160–1172.e3. doi:10.1016/j.jaac.2012.08.024.

Wass, S., Porayska-Pomsta, K., & Johnson, M. H. (2011). Training attentional control in infancy. *Current Biology, 21*(18), 1543–1547. doi:10.1016/j.cub.2011.08.004.

Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience, 6*, 41. doi:10.3389/fnhum.2012.00041.

Adult Lifespan

Sabrina Guye, Christina Röcke, Susan Mérillat,
Claudia C. von Bastian, and Mike Martin

Introduction

There is robust longitudinal evidence for age-related decline in cognitive abilities. Fluid abilities are affected earlier than crystallized abilities, but with varying onset and slope between individuals (e.g., Salthouse 2010). These negative age-related changes have sparked early interest in the possibility of preventing or counteracting this decline and thus maintaining cognitive health into later life with cognitive training interventions. In this chapter, we review the literature regarding training-induced plasticity in healthy older adults.

Many of the early training interventions focused on improving (episodic) memory ability, given that subjective changes in one's memory functioning are frequently voiced concerns from older adults (see also Wenger and Shing this volume). Using a testing-the-limits paradigm, these training interventions typically instructed participants in a specific memory strategy, such as the method of loci, trying to uncover the strategy-independent latent performance potential and the boundary

---

S. Guye (✉) • C. Röcke • S. Mérillat
University Research Priority Program (URPP) "Dynamics of Healthy Aging",
University of Zurich, Zurich, Switzerland
e-mail: sabrina.guye@uzh.ch; christina.roecke@uzh.ch; susan.merillat@uzh.ch

C.C. von Bastian
Cognition and Cognitive Neuroscience Research Centre, Department of Psychology,
Bournemouth University, Bournemouth, England
e-mail: cvonbastian@bournemouth.ac.uk

M. Martin
University Research Priority Program (URPP) "Dynamics of Healthy Aging",
University of Zurich, Zurich, Switzerland

Division of Gerontopsychology, Department of Psychology, University of Zurich,
Zurich, Switzerland
e-mail: m.martin@psychologie.uzh.ch

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_5

conditions for such latent reserve capacity of the aging cognitive system. The second generation of cognitive training interventions consisted of process-based approaches that focused on broader, more basic cognitive processes including working memory (see also Karbach and Strobach this volume) or executive functions (see also Karbach and Kray this volume). As a special form of process-based training, newer approaches target multiple cognitive domains simultaneously to achieve broader and larger transfer and greater ecological validity.

In the first part of this chapter, we review empirical evidence regarding the benefits of cognitive training interventions in healthy older adults separately for training gains, transfer, and their maintenance, as well as findings regarding brain structure and function. In the second part, we will outline key points to consider in future research to design more effective training interventions for healthy older adults to help maintain cognitive functioning.

Benefits of Cognitive Training Interventions

Cognitive training studies differ on a multitude of design choices (e.g., type of training and its administration, cognitive domain, setting, intensity and duration, type of control group, and type of outcome measure to assess training effectiveness). In addition, the systematic reviews and meta-analyses available also differ substantially in their scope and inclusion criteria, and whether they distinguish between training gain and transfer effects and between different types of control groups. Thus, conclusions from these overview analyses are not straightforward to compare.

Evidence for Training Effects

Training Gains: *Passive vs. Active Controls*. Training effects are typically operationalized as pre- to post-training performance increases on the trained tasks compared to pre- to post-training performance changes in *passive* (i.e., with no instructed activity) or *active* control groups (i.e., with an instructed activity, but clear differentiation in the involved cognitive processes; Shipstead et al. 2012). Findings across different kinds of interventions indicate cognitive plasticity in terms of training gains (e.g., Baltes and Kliegl 1992). For example, in their meta-analysis on process-based working memory and executive functioning training, Karbach and Verhaeghen (2014) reported raw training gains of 0.9 *SD*, which remained almost equal in size when compared to passive controls (0.8 *SD*; see also Kelly et al. 2014 for similar effect sizes in working memory and speed training interventions). Interestingly, however, training gains were found as reduced to 0.5 *SD* (Karbach and Verhaeghen 2014) or even zero (Martin et al. 2011, see also Kelly et al. 2014 for replication) after comparing to active controls. Promising training gains emerge for multi-domain training interventions (Park et al. 2014, see also Green et al. this volume).

Age-Related Differences in Training Gains. In contrast to findings from strategy-based training interventions indicating a magnification of age differences in cognitive performance and limits to training-induced plasticity in the very old (e.g., Verhaeghen and Marcoen 1996), no such age differences in training gains were observed for process-based working memory and executive functioning training interventions (Karbach and Verhaeghen 2014). The implementation of complex cognitive strategies may require a higher level of cognitive functioning than is true for the elementary cognitive processes targeted in process-based training interventions (Verhaeghen 2014). While research concerning multi-domain training is still in its infancy, there is initial evidence for greater video game training benefits for older-old compared to younger-old adults, but the underlying reasons are yet poorly understood (see also Green et al. this volume, Strobach and Schubert this volume).

Moderators of Training Effectiveness. Group-based lab settings show greater effects than home-based training interventions (Kelly et al. 2014; Lampit et al. 2014), but it remains unclear whether these differences are due to formal vs. informal instruction or to the social setting vs. being alone. The same is true for training frequency and duration, where there is conflicting evidence about whether shorter or longer duration is most beneficial (Karbach and Verhaeghen 2014; Kelly et al. 2014).

Evidence for Transfer Effects

As discussed in the paragraphs above, training interventions improve performance on the trained task, with greater gains compared to passive than active controls, and more robust effects for process- than strategy-based training interventions. Some of the training gains reported were of equivalent size as normal age-related declines across various cognitive domains, suggesting that training interventions likely help to reverse age-related declines and thus to stabilize cognitive functioning (Ball et al. 2002). The question is, however, if these improvements transfer to untrained tasks measuring either the same ability (i.e., near transfer) or to tasks measuring different abilities sharing underlying cognitive processes (i.e., far transfer; see, e.g., Noack et al. 2009; Shipstead et al. 2012).

Transfer to Other Cognitive Tasks Assessed in the Laboratory. For strategy-based trainings, little to no transfer effects have been found (e.g., Martin et al. 2011). It has been argued, though, that in contrast to the acquisition of specific memory strategies, practice effects from process-based training would be more prone to induce transfer to other cognitive tasks sharing the same core processes as the ones targeted in the intervention (e.g., Shipstead et al. 2012). Indeed, most process-based cognitive training interventions successfully lead to small to moderate near transfer effects when the training is adaptive and of longer duration (Kelly et al. 2014). For training interventions targeting working memory and executive functioning, for example, Karbach and Verhaeghen's (2014) meta-analysis indicated a net gain in near transfer tasks compared to active controls of 0.5 *SD*. However, far transfer effects were very small (net far transfer effects 0.2 *SD* in Karbach and Verhaeghen

2014). The few available multi-domain training interventions including cognitively complex group activities (e.g., Park et al. 2014), problem solving (Stine-Morrow et al. 2008), or video games (see Green et al. this volume, Strobach and Schubert this volume) have also shown small to moderate transfer effects to some cognitive functions, including executive functioning, episodic memory, or processing speed. However, in order to design effective training interventions in the future, the understanding of the underlying processes, the cognitive functions targeted, and a high degree of ecological validity are necessary (see also Binder et al. 2015).

Transfer to Everyday Life. Transfer to everyday life has been examined in only few studies, and some recent reviews have even excluded studies with everyday transfer from their analysis (e.g., Lampit et al. 2014). When examined, everyday life has mainly been operationalized in terms of self-reported basic or instrumental activities of daily living (BADL/IADL) and, thus, measures of everyday competence impairments that are not necessarily optimal indicators of everyday functioning in healthy older adults due to ceiling effects. In the ACTIVE trial, the speed of information processing in everyday life was assessed by tasks such as looking up a telephone number, finding a respective food item on the supermarket shelf, identifying the ingredients on food labels, as well as self-reported driving ability. Not surprisingly, little to no evidence of transfer of the memory, reasoning, and processing speed training interventions to impairments in everyday functioning has been found immediately after training (Ball et al. 2002).

Evidence for Maintenance Effects

Most studies assess pretest and immediate posttest performance and transfer, but do not follow up on these effects over extended periods of time. Many studies examine maintenance only across a few months, even though it has been proposed that a 3-year interval is more appropriate for a sensitive test of maintenance and differential stability and change effects (Salthouse 2006).

Maintenance of Training Gains. Kelly et al. (2014) report maintenance effects examined after up to 6 months, indicating maintenance of training gains following executive functioning and memory training interventions. Longer follow-up intervals have been included in selected studies, such as the ACTIVE trial (Rebok et al. 2014; Willis et al. 2006), covering 5-year and 10-year post-training assessments. In the ACTIVE study, training gains observed in each training group were maintained over 5 years, with indication of positive additional effects through intermediate booster training (Willis et al. 2006). After 10 years, training effects were maintained in the reasoning and processing speed domains, but no longer in the episodic memory domain (Rebok et al. 2014).

Maintenance of Transfer Effects. Even though immediate or shorter-term effects after 2 years were not found in the ACTIVE trial (Ball et al. 2002), there are promising transfer effects to everyday functioning after longer periods for particular training conditions and everyday outcomes: (process-based) speed training was related to better driving performance and self-reported driving experience after up to 6-year intervals (Ball et al. 2010). In addition, there is evidence for effects of training on the slope of change trajectories in everyday functioning: across a 5-year interval, participants in the (strategy-based) reasoning training group showed less steep declines in BADL/IADL competence and a 50 % reduced risk of experiencing a car accident compared to the passive control participants (Willis et al. 2006). After an extended time period of 10 years, ACTIVE data showed transfer to everyday functioning in terms of BADL/IADL for all three training conditions, suggesting that trained individuals experienced fewer impairments in their independent functioning in everyday life. Interestingly, at the long-term follow-up and an average age of 82 years, 60 % of the trained participants were at or above their baseline everyday competence level, which was true for only 50 % of the passive control participants. The summarized findings indicate that transfer effects on the ability to live independently apparently can become detectable or play out in the long run rather than immediately following the training intervention. Outcome measures assessing everyday performance above impairment level or everyday cognitive activities instead of abilities have hardly been used in the literature so far, but may be more promising to detect transfer to real life.

Evidence for Effects on Brain Structure and Function

Normal aging is accompanied by brain tissue loss and neurophysiological changes (Raz and Rodrigue 2006). While the loss of gray matter manifests itself as general volume decline and cortical thinning (Fjell and Walhovd 2010), the degradation of white matter is reflected in reduced integrity and the incidence of so-called white matter hyperintensities. With respect to brain function, aging has been linked with a complex pattern of local over- and under-recruitment of neural resources.

Effects on Brain Structure. A growing number of structural neuroimaging studies in healthy older adults provide evidence for beneficial effects of cognitive training on brain structure, especially for the domains of memory and working memory, where most of the work has been carried out. These effects (compared to a control group) comprise reduced decreases, maintenance or even increases in volume or cortical thickness of brain structures relevant for the trained function (e.g., Raz et al. 2013; Lövdén et al. 2012). The integrity of white matter, which can be qualified by different measures of water diffusion (e.g., fractional anisotropy, FA) on the basis of diffusion tensor imaging (DTI), can also be maintained or even increased by cognitive training interventions (e.g., Engvig et al. 2012). The reported effects reflect processes of structural neuroplasticity, which (partly) counteract the tissue degradation normally observed with aging. However, as most of the previous studies used passive control groups only, future studies including active control groups need to confirm the specificity of such effects.

Effects on Brain Function. The evidence emerging from studies investigating the effects of cognitive training interventions on brain function is less conclusive. On the one hand, studies adopting strategy-based training interventions report increased brain activity during post-training task performance (e.g., Nyberg et al. 2003). Based on the observed correlations between neurophysiological and behavioral changes, the activation increase has been attributed to an enhanced recruitment of task-specific regions that enables behavioral gains. On the other hand, process-based training studies, particularly in the domains of working memory or executive functioning, showed decreased brain activity at post- compared to pre-training assessment, indicating improved neural efficiency during post-training task performance (e.g., Brehmer et al. 2011). This discrepancy in the pattern of activity might be due to the different neural mechanisms initiated by the different training types. However, there is evidence in younger adults that the activity decrease seen at later phases of process-based training interventions is actually preceded by an increase of activity in early training phases (Hempel et al. 2004). Future studies need to confirm whether this trajectory holds for older adults and whether strategy-based training interventions would also lead to increased neural efficiency after an extended period of implementing the acquired strategies.

Using electroencephalography (EEG), recent studies in older adults have demonstrated facilitative effects of cognitive training on early electrophysiological markers of the trained cognitive function with the extent of the ERP change predicting post-training performance (e.g., Berry et al. 2010).

What to Consider When Developing Future Training Interventions

Despite several promising results emerging from the field, a number of contradictory findings about training and transfer effects exist. However, the nature of this inconsistency remains unclear, and studies on key areas of training evaluation, including transfer to everyday performance and the embedding of training interventions into real-life contexts, are scarce at best. This section gives an overview on some methodological factors and individual differences that potentially influence training outcomes (see also Schmiedek this volume, and for reviews see Noack et al. 2009; Shipstead et al. 2012; von Bastian and Oberauer 2014). Moreover, this section highlights the importance of capturing daily life functioning in the context of cognitive training interventions and transfer assessments.

Methodological Issues

Sufficient Power. Low statistical power due to small sample sizes is a prevailing issue in training studies, which is especially pronounced in the field of gerontology. In Kelly et al.'s (2014) meta-analysis, nearly 60 % of the included studies based their analyses on group sizes smaller than 40 participants. Bogg and Lasecki (2015) concluded that the mean power estimate across working memory training studies is 11 %. This finding emphasizes that low statistical power increases the risk of false-negative results (i.e., missing effects by erroneously accepting the null hypothesis). Consequently, to correctly estimate the effectiveness of cognitive training interventions, it is crucial to conduct well-powered studies despite the logistical and financial challenges.

Active Control Groups. Using active control groups is still not common practice. Again, Kelly et al. (2014) reported that only 10 out of 24 studies included active control groups, whereas 14 studies relied on a no-intervention control group. However, passive control groups do not control for non-specific sources of improvement such as motivational aspects, expectancy effects, or effects from general cognitive stimulation. Consequently, passive controls do not allow to test for training-specific effects, but only control for test-retest effects. Thus, it is important that active control groups only differ in the process that is being trained, but are identical in all other intervention-specific factors that could potentially influence the size or scope of transfer in order to make a true evaluation of unique training effects possible.

Abilities Instead of Skills. The ultimate goal of cognitive training interventions in older age is to stabilize or enhance cognitive abilities relevant to everyday life. To ensure that training and transfer effects reflect changes in the underlying cognitive ability and not just particular task-specific skills, it is necessary to demonstrate transfer on the level of abilities by assessing it with multiple indicators (e.g., Noack et al. 2009). Ideally, change is evaluated on the latent level using structural equation modeling. Latent variables have the advantage of containing only the common variance (without the measurement error) among the tasks that are used as indicators, thus increasing the measurement validity.

Inter- and Intraindividual Differences

Although the effectiveness of cognitive training interventions is typically examined at the group level, there is evidence indicating that individual differences such as personality traits (e.g., lower levels neuroticism and higher levels conscientiousness) and lower baseline cognitive ability are related to higher training and/or transfer effects (see Katz et al. this volume, and for a review see von Bastian and Oberauer 2014). Further, at least in young adults, intraindividual couplings between affect and cognitive performance have been reported (e.g., Brose et al. 2012). However, it is important to note these concepts are not immutable, but underlie dynamic processes across the lifespan. For instance, personality undergoes changes from childhood until very old age. Interestingly, the trajectories across different personality traits are rather heterogeneous: whereas some traits show continuous mean-level increases (e.g., conscientiousness), others remain stable (e.g., social vitality; Roberts and Mroczek 2008). Further, when it comes to affect, young and older adults show small differences in their average level of negative or positive affect typically favoring older adults, but they differ significantly in the amount of intraindividual affective variability and reactivity to daily events (e.g., Röcke et al. 2009). Still, studies investigating individual differences in the context of training in older adults are scarce.

To summarize, assessing inter- and intraindividual differences in the context of evaluating training-related effects is important for two reasons. Firstly, it deepens the understanding of possible moderators of the effectiveness of cognitive training interventions in older adults. Secondly, the identification of moderators is an important step toward individually tailored training approaches (see also Colzato and Hommel this volume).

Capturing Daily Life in Training and Transfer

The majority of training studies has focused primarily on lab-based measures when examining cognitive abilities in older age. However, psychometric properties of commonly used transfer tasks measure *maximum performance*, that is, how participants perform when expending their maximum effort. Despite the consistent finding that younger adults outperform older adults in many of these lab-based tasks, many older adults report high levels of sense of control and life satisfaction, indicating that they successfully manage their daily lives (e.g., Scheibe and Carstensen 2010). The disconnection between findings in cognitive functioning emerging from the lab (*maximum-level* cognition) and observations in daily life (*activity-based* cognition) is still understudied and not well understood (Verhaeghen et al. 2012).

In order to assess the effectiveness of a training intervention in older adults, it is therefore important to investigate cognitive improvements by including lab-based measures closer to everyday life. Preferably, though, it should be standard to systematically assess transfer in real life in addition to lab-based measures (e.g., Rebok et al. 2014). Similarly, a large part of the computer-based cognitive training interventions contain standard cognitive tasks. Another way to go *from lab to life* is to adopt video games or serious games containing tasks that more appropriately match everyday life challenges (Binder et al. 2015) or to directly engage in novel and cognitively demanding activities such as quilting or digital photography (Park et al. 2014; Stine-Morrow et al. 2008).

Cognitive training interventions often lack ecological validity, and comprehensive, reliable, and valid test batteries for assessing training-related improvements in real life are scarce (but see Mazurek et al. 2015). In this vein, it could be beneficial for training researchers to join forces with aging researchers in examining the effects of older adults' living environments on cognition and overall functioning to find appropriate daily life training and transfer tasks (Wahl et al. 2012).

Acknowledgments Part of this work was supported by a grant and financial support awarded to the first author from the Suzanne and Hans Biäsch Foundation for Applied Psychology and the Jacobs Foundation. Moreover, this work was supported by the University Research Priority Program "Dynamics of Healthy Aging" of the University of Zurich.

During the work on her dissertation, Sabrina Guye was a predoctoral fellow of LIFE (International Max Planck Research School on the Life Course; participating institutions: MPI for Human Development, Humboldt-Universität zu Berlin, Freie Universität Berlin, University of Michigan, University of Virginia, and University of Zurich).

References

Ball, K. K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., et al. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *The Journal of the American Medical Association, 288*(18), 2271–2281. doi:10.1001/jama.288.18.2271.

Ball, K. K., Edwards, J. D., Ross, L. A., & McGwin, G. (2010). Cognitive training decreases motor vehicle collision involvement of older drivers. *Journal of the American Geriatrics Society, 58*(11), 2107–2113. doi:10.1111/j.1532-5415.2010.03138.x.

Baltes, P. B., & Kliegl, R. (1992). Further testing of limits of cognitive plasticity: Negative age differences in a mnemonic skill are robust. *Developmental Psychology, 28*(1), 121–125. doi:10.1037/0012-1649.28.1.121.

Berry, A. S., Zanto, T. P., Clapp, W. C., Hardy, J. L., Delahunt, P. B., Mahncke, H. W., et al. (2010). The influence of perceptual training on working memory in older adults. *PLoS One, 5*(7), e11537. doi:10.1371/journal.pone.0011537.

Binder, J. C., Zöllig, J., Eschen, A., Mérillat, S., Röcke, C., Schoch, S. F., et al. (2015). Multi-domain training in healthy old age: Hotel Plastisse as an iPad-based serious game to systematically compare multi-domain and single-domain training. *Frontiers in Aging Neuroscience, 7*, 137. doi:10.3389/fnagi.2015.00137.

Bogg, T., & Lasecki, L. (2015). Reliable gains? Evidence for substantially underpowered designs in studies of working memory training transfer to fluid intelligence. *Frontiers in Psychology, 5*, 1589. doi:10.3389/fpsyg.2014.01589.

Brehmer, Y., Rieckmann, A., Bellander, M., Westerberg, H., Fischer, H., & Bäckman, L. (2011). Neural correlates of training-related working-memory gains in old age. *NeuroImage, 58*(4), 1110–1120. doi:10.1016/j.neuroimage.2011.06.079.

Brose, A., Schmiedek, F., Lövdén, M., & Lindenberger, U. (2012). Daily variability in working memory is coupled with negative affect: The role of attention and motivation. *Emotion, 12*(3), 605–617. doi:10.1037/a0024436.

Engvig, A., Fjell, A. M., Westlye, L. T., Moberget, T., Sundseth, Ø., Larsen, V. A., et al. (2012). Memory training impacts short-term changes in aging white matter: A longitudinal diffusion tensor imaging study. *Human Brain Mapping, 33*(10), 2390–2406. doi:10.1002/hbm.21370.

Fjell, A. M., & Walhovd, K. B. (2010). Structural brain changes in aging: Courses, causes and cognitive consequences. *Reviews in the Neurosciences, 21*(3), 187–221. doi:10.1515/REVNEURO.2010.21.3.187.

Hempel, A., Giesel, F. L., Garcia Caraballo, N. M., Amann, M., Meyer, H., Wüstenberg, T., et al. (2004). Plasticity of cortical activation related to working memory during training. *The American Journal of Psychiatry, 161*(4), 745–747. doi:10.1176/appi.ajp.161.4.745.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*(11), 2027–2037. doi:10.1177/0956797614548725.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta-analysis. *Ageing Research Reviews, 15*, 28–43. doi:10.1016/j.arr.2014.02.004.

Lampit, A., Hallock, H., & Valenzuela, M. (2014). Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. *PLoS Medicine, 11*(11), e1001756. doi:10.1371/journal.pmed.1001756.

Lövdén, M., Schaefer, S., Noack, H., Bodammer, NC., Kühn, S., Heinze, H.J., Düzel, E., Bäckman, L., Lindenberger, U. (2012). Spatial navigation training protects the hippocampus against age-related changes during early and late adulthood. *Neurobiology of Aging, 33*(3),620.e9. doi: 10.1016/j.neurobiolaging.2011.02.013.

Martin, M., Clare, L., Altgassen, A. M., Cameron, M. H., & Zehnder, F. (2011). Cognition-based interventions for healthy older people and people with mild cognitive impairment. *Cochrane Database of Systematic Reviews, 1*, CD006220. doi:10.1002/14651858.CD006220.pub2.

Mazurek, A., Bhoopathy, R. M., Read, J. C. A., Gallagher, P., & Smulders, T. V. (2015). Effects of age on a real-world what-where-when memory task. *Frontiers in Aging Neuroscience, 7*, 74. doi:10.3389/fnagi.2015.00074.

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: Gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience, 27*(5), 435–453. doi:10.3233/RNN-2009-0496.

Nyberg, L., Sandblom, J., Jones, S., Stigsdotter Neely, A., Petersson, K. M., Ingvar, M., et al. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences, 100*(23), 13728–13733. doi:10.1073/pnas.1735487100.

Park, D. C., Lodi-Smith, J., Drew, L., Haber, S., Hebrank, A., Bischof, G. N., & Aamodt, W. (2014). The impact of sustained engagement on cognitive function in older adults: The synapse project. *Psychological Science, 25*(1), 103–112. doi:10.1177/0956797613499592.

Raz, N., Schmiedek, F., Rodrigue, K. M., Kennedy, K. M., Lindenberger, U., & Lövdén, M. (2013). Differential brain shrinkage over 6 months shows limited association with cognitive practice. *Brain and Cognition, 82*(2), 171–180. doi:10.1016/j.bandc.2013.04.002.

Raz, N., & Rodrigue, K. M. (2006). Differential aging of the brain: Patterns, cognitive correlates and modifiers. Neuroscience & Biobehavioral Reviews, 30(6), 730–748. doi: 10.1016/j.neubiorev.2006.07.001.

Rebok, G. W., Ball, K. K., Guey, L. T., Jones, R. N., Kim, H., King, J. W., et al. (2014). Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society, 62*(1), 16–24. doi:10.1111/jgs.12607.

Roberts, B. W., & Mroczek, D. (2008). Personality trait change in adulthood. *Current Directions in Psychological Science, 17*(1), 31–35. doi:10.1111/j.1467-8721.2008.00543.x.

Röcke, C., Li, S.-C., & Smith, J. (2009). Intraindividual variability in positive and negative affect over 45 days: Do older adults fluctuate less than young adults? *Psychology and Aging, 24*(4), 863–878. doi:10.1037/a0016276.

Salthouse, T. A. (2006). Mental exercise and mental aging. evaluating the validity of the "use it or lose it" hypothesis. *Perspectives on Psychological Science, 1*(1), 68–87. doi:10.1111/j.1745-6916.2006.00005.x.

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society, 16*(5), 754–760. doi:10.1017/S1355617710000706.

Scheibe, S., & Carstensen, L. L. (2010). Emotional aging: Recent findings and future trends. *The Journals of Gerontology: Psychological Sciences, 65B*(2), 135–144. doi:10.1093/geronb/gbp132.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin, 138*(4), 628–654. doi:10.1037/a0027473.

Stine-Morrow, E. A. L., Parisi, J. M., Morrow, D. G., & Park, D. C. (2008). The effects of an engaged lifestyle on cognitive vitality: A field experiment. *Psychology and Aging, 23*(4), 778–786. doi:10.1037/a0014341.

Verhaeghen, P. (Ed.). (2014). *The elements of cognitive aging: Meta-analyses of age-related differences in processing speed and their consequences*. New York, NY: Oxford University Press.

Verhaeghen, P., & Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: Evidence for an amplification model. *Psychology and Aging, 11*(1), 164–178. doi:10.1037/0882-7974.11.1.164.

Verhaeghen, P., Martin, M., & Sędek, G. (2012). Reconnecting cognition in the lab and cognition in real life: The role of compensatory social and motivational factors in explaining how cognition ages in the wild. *Neuropsychology, Development, and Cognition. Section B. Aging, Neuropsychology, and Cognition, 19*(1–2), 1–12. doi:10.1080/13825585.2011.645009.

von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: A review. *Psychological Research, 78*(6), 803–820. doi:10.1007/s00426-013-0524-6.

Wahl, H.-W., Iwarsson, S., & Oswald, F. (2012). Aging well and the environment: Toward an integrative model and research agenda for the future. *Gerontologist, 52*(3), 306–316. doi:10.1093/geront/gnr154.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K. K., Elias, J., Koepke, K. M., et al. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association, 296*(23), 2805–2814. doi:10.1001/jama.296.23.2805.

Part III
Plasticity of Different Cognitive Domains

Working Memory

Tanja Könen, Tilo Strobach, and Julia Karbach

Introduction: Definition, Models, and the Significance of Working Memory

Working memory (WM) allows for simultaneously maintaining and processing information in a controlled manner (Baddeley and Hitch 1994). Several competitive theoretical models of WM are existing and are still vividly discussed (Baddeley 2012; Wilhelm et al. 2013; for reviews). Most WM models contributed substantially to our current understanding of WM and largely agree on the basic assumptions that WM capacity is limited and that reliable individual differences in this capacity exist, which place limiting constraints for performing a wide range of other cognitive activities (e.g., Baddeley 2012; Oberauer 2009). In other words, WM is a limited capacity system providing the temporary storage and manipulation of information that is necessary for higher cognitive functioning (e.g., for reasoning; Baddeley 2012). The WM models do, however, significantly differ in the assumptions about the structure of this limited capacity system. We will shortly introduce the main ideas of the models of Oberauer, Baddeley, Miyake, and colleagues because they are particularly helpful for understanding well-known WM training paradigms.

Oberauer defines WM as the cognitive system that allows for building, maintaining, and updating structural representations via dynamic bindings (cf. Oberauer 2009; Wilhelm et al. 2013). This WM system consists of two parts: bindings temporarily organize information such as words, objects, or events in a declarative part and connect this information to allowed or inhibited responses in a procedural part

---

T. Könen (✉) • J. Karbach
Department of Psychology, Goethe-University Frankfurt, Frankfurt, Germany
e-mail: koenen@psych.uni-frankfurt.de; karbach@psych.uni-frankfurt.de

T. Strobach
Department of Psychology, Medical School Hamburg, Hamburg, Germany
e-mail: tilo.strobach@medicalschool-hamburg.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_6

(Oberauer 2009). Baddeley, however, defines WM as a cognitive system with at least three components: the central executive, which is responsible for focusing and dividing attention and for coordinating the information flow between at least two temporary storage systems, one for phonological and one for visuospatial information (Baddeley and Hitch 1994). Miyake emphasizes the special role of WM updating (i.e., monitoring and refreshing information held in WM) as an executive function (Miyake et al. 2000; Karbach and Kray this volume; Strobach and Schubert this volume).

Taken together, these WM models differ in the assumed underlying structure of the WM system but agree that it allows for simultaneously maintaining and processing information. Because of this fundamental function, it is not surprising that WM has shown to be a central determinant of fluid intelligence (e.g., Kane et al. 2004), school achievements in various domains (Titz and Karbach 2014), and a large number of other cognitive tasks that are highly relevant in daily life (e.g., language comprehension, following directions, and writing; see Barrett et al. 2004, for a review).

The Rationale Behind Working Memory Training

The idea that WM capacity is the main limiting factor for performing a wide range of cognitive activities (e.g., Baddeley 2012) has the implication that WM training could not only benefit WM functioning but a wide range of cognitive functions. Thus, in addition to performance improvements on the trained WM tasks and near transfer to other non-trained WM tasks, one might even expect far transfer to a range of alternative functions. For example, given the close relation of WM capacity and fluid intelligence (e.g., Kane et al. 2004), one could assume that WM training might also benefit reasoning. Improving WM functioning even slightly might therefore have enormous practical implications relevant to everyday life.

Two general mechanisms could mediate transfer effects: enhanced WM capacity and/or enhanced efficiency using the available WM capacity (cf. von Bastian and Oberauer 2014). Enhancing WM capacity is the traditional goal of WM training and a classic explanation for transfer effects (see Klingberg 2010, for a review). Enhanced efficiency has long been considered to be largely material or process specific, for example, through the acquisition of strategies suited for a specific task paradigm only. Although recent evidence suggests that enhanced efficiency could also work on a more general level, such as faster visual encoding or faster attentional processes (von Bastian and Oberauer 2014), enhancing WM capacity remains the aim and focus of most training studies. WM training is assumed to enhance general WM capacity if there is evidence for transfer effects to multiple WM tasks varying in the type of material and mode of testing (Klingberg 2010).

Enhanced WM capacity can theoretically be explained with training-induced cognitive plasticity (Lövdén et al. 2010; see also Karbach and Kray this volume). Plasticity denotes that a prolonged mismatch between cognitive resources and situational demands can foster reactive changes in the possible ranges of individual cognitive performance – such as changes in WM capacity (cf. Lövdén et al. 2010). To create a prolonged mismatch, WM training needs to be challenging but manageable with a high degree of effort. No mismatch arises if the WM tasks can either be solved with the existing WM capacity or if they are so frustrating that participants give up. Therefore, WM training groups are often assigned to adaptive task-difficulty conditions to foster plasticity by keeping WM demands perpetually at the individual limit, whereas active control groups are assigned to consistently low WM task-difficulty conditions or tasks tapping on functions alternative to WM (cf. Lövdén et al. 2010).

Selected Training Regimes

A basic distinction can be drawn between single-paradigm training regimes, focusing on one WM paradigm, multi-paradigm regimes including multiple WM paradigms, and multi-domain regimes including not only WM tasks but also tasks drawing on other abilities (e.g., on processing speed; von Bastian and Oberauer 2014). Naturally, single-paradigm regimes have the advantage that training and transfer effects can be attributed to specific mechanisms more easily. Multi-paradigm or multi-domain regimes could in theory be more effective because they require more heterogeneous cognitive processes, but the effects cannot be isolated. However, there is rarely any empirical evidence directly comparing different WM training regimes (but see von Bastian and Oberauer 2013). Most studies investigate the effectiveness of a specific regime. We will shortly introduce a selection of well-known WM training regimes.

Simple Span Training. In simple span tasks, participants have to recall a list of stimuli (e.g., digits or colors) after a brief retention interval. In case of successful recall, they are given a longer list of stimuli. Recall takes place in either the presented order (e.g., digit span forwards) or in reverse order (e.g., digit span backwards). Recall in the presented order requires temporary storage and thus draws on the storage systems assumed in Baddeley's WM model. Backward span tasks draw on central executive functioning. Therefore, training regimes based on Baddeley's WM model usually include both forward and backward span tasks to train all components of WM. The probably best known regime based on simple span tasks is *Cogmed* WM training (www.cogmed.com), which is very common, particularly for children with ADHD. *Cogmed* has been tested in a large number of studies and is the topic of several ongoing discussions and current reviews (e.g., Shinaver et al. 2014).

Complex Span Training. Complex span tasks combine simple span tasks with a simultaneous and often unrelated secondary task, such as evaluating equations or pictures. Thus, they draw on both storage and processing, which particularly correspond with Baddeley's WM model (which includes storage and processing units). Recent empirical evidence suggests that they are almost perfectly correlated with binding and updating tasks (e.g., Wilhelm et al. 2013) and can thus also be mapped to Oberauer's WM model. Complex span tasks are well-established and popular indicators of WM capacity (e.g., Kane et al. 2004), which are regularly used as training tasks in cognitive training. For example, they are implemented in the WM training battery *Braintwister* (Buschkuehl et al. 2008) and the WM tasks in *Tatool* (von Bastian et al. 2013).

N-Back Training. In the *n*-back task, participants are presented with sequences of stimuli and must decide whether the current stimulus matches the one presented *n* items back in a given modality (e.g., visuospatial or auditory). Importantly, *n* is a variable number that can be adjusted to increase or decrease task difficulty. Dual *n*-back tasks combine two modalities and are considered to be more difficult and effective than single *n*-back tasks. The *n*-back task is a valid indicator of WM capacity (e.g., Wilhelm et al. 2013, but see Jaeggi et al. 2010) and particularly corresponds with the theoretical understanding of Oberauer and Miyake as it requires the updating of information in WM. Cognitive training with *n*-back tasks is common in various age groups and is implemented in, for example, the *Braintwister* WM training battery (Buschkuehl et al. 2008) and the *Lumosity* cognitive training battery (e.g., Hardy et al. 2015).

Training and Transfer Effects

To evaluate the effectiveness of WM training, one considers whether a training group (compared to a control group) showed (1) performance improvements on the trained WM tasks, (2) near transfer to non-trained WM tasks, and (3) far transfer to different cognitive functions.

Training Effects. WM training studies ubiquitously report that trained participants significantly improve their performance on the trained WM task(s) over the course of training (cf. Morrison and Chein 2011). This applies to a wide variety of training regimes and age ranges of the participants. Even generally critical reviews acknowledge that participants typically advance considerably (e.g., Shipstead et al. 2012). In a meta-analytical integration of 12 WM training effects derived from studies with older adults, we found a large average standardized increase between pre- and posttest of $d = 1.1$ compared to the control groups (Karbach and Verhaeghen 2014). While average comparisons of standardized pre- and posttest performances are a classical requirement in WM training studies, analyzing individual performance trajectories over the course of training sessions can even provide additional information. For example, by comparing the individual performance growth of younger and older adults, Bürki and colleagues (2014) demonstrated that older adults showed on average a slower WM performance growth during training than younger adults.

However, improved performance on a training task does not necessarily imply an enhanced WM capacity (Shipstead et al. 2012). The conclusion of training-induced increases in WM capacity is only valid in comparison to an adequate control group (e.g., see Green et al. 2014, for a review) and with evidence for near transfer effects to multiple WM tasks varying in the type of material and mode of testing (Klingberg 2010).

Near Transfer Effects. A large number of recent meta-analyses and reviews agree that WM memory training produces near transfer to non-trained WM tasks in children, younger adults, and older adults (e.g., Karbach and Verhaeghen 2014; Melby-Lervåg and Hulme 2013; Schwaighofer et al. 2015). For example, in a meta-analytical integration of 18–21 near transfer effects derived from studies with children and adults, Melby-Lervåg and Hulme (2013) found moderate and large average standardized increases on visuospatial/verbal WM tasks of $d = 0.5/0.8$ between pre- and posttest compared to control groups. Age was a significant moderator of the effect on verbal WM, with children showing larger benefits than adolescents (Melby-Lervåg and Hulme 2013). Notably, near transfer effects are usually smaller than training effects. For example, with *Cogmed* training for children, improvements in trained tasks were about 30–40 %, whereas improvements in non-trained WM tasks were about 15 % (cf. Klingberg 2010; see also Karbach and Verhaeghen 2014 for similar findings on older adults).

Despite this promising evidence, it is important to consider that not all studies have minimized task-specific overlaps between the training and near transfer tasks (cf. Shipstead et al. 2012). Ideally, transfer should be evaluated on the latent ability level (see Schmiedek this volume for details). Evidence for near transfer on the latent ability level would be strong evidence for training-induced increases in WM capacity and thus an optimal foundation for the investigation of far transfer effects.

Far Transfer Effects. The question whether valid far transfer effects to different cognitive functions exist is highly controversial. They would be a central determinant of the value of WM interventions because training outcomes need to generalize to other cognitive abilities to optimally support participants in their daily life. Most views on transfer suggest that the likelihood and strength of far transfer varies as a function of the similarity in processing demands between the training and transfer tasks (see Taatgen this volume for details). Thus, one would expect transfer to abilities that are generally known to be strongly related to WM, such as, for example, fluid intelligence, executive functions, and academic achievement. The evidence for far transfer effects, however, is mixed. Recent meta-analyses on WM training differed in the conclusion on the presence (Au et al. 2015, 2016; Karbach and Verhaeghen 2014; Schwaighofer et al. 2015) or absence of far transfer effects (Melby-Lervåg and Hulme 2013, 2016).

For example, the meta-analysis of Au and colleagues (2015) focused on fluid intelligence as transfer outcome. They integrated 24 effect sizes of *n*-back training with healthy adults (18–50 years of age) and found small average standardized increases on fluid intelligence tasks of Hedges's $g = 0.2$ between pre- and posttest compared to control groups. The meta-analysis of Schwaighofer et al. (2015) on this issue comes to a similar conclusion, while another one does not (Melby-Lervåg and Hulme 2013). This is not surprising because different selection criteria can result in different samples and findings. For instance, Melby-Lervåg and Hulme (2013) included studies investigating different age groups from all over the lifespan (up to 75 years of age), and they did not differentiate between healthy and cognitively impaired participants. Considering the large individual differences in the magnitude of transfer effects and the evidence that low-performing individuals tend to benefit more from WM training than high-performing individuals (see Karbach and Unger 2014, for a review), it is not surprising that data averaged over these very diverse groups do not show any significant far transfer effects on the group level. However, more evidence is needed before a converging view on far transfer to fluid intelligence can evolve in the field. Interestingly, Bürki and colleagues (2014) analyzed the individual performance growth in WM training with younger and older adults and found that those who improved more during training showed higher gains in a fluid intelligence transfer task. This is a correlational and by no means a causal finding, but it can help to understand individual differences in transfer outcomes.

Further, first evidence shows far transfer to executive functions (e.g., Melby-Lervåg and Hulme 2013; Salminen et al. 2012), but a complete picture with findings on all age ranges and all executive functions is yet missing. For example, the meta-analyses of Melby-Lervåg and Hulme (2013) including children and adults demonstrated small transfer effects to inhibition (Stroop task, $d=0.3$, 10 effect sizes) but did not include updating or task switching.

Concerning far transfer to academic achievement, the present findings on children demonstrate converging evidence for positive effects on reading but not mathematics (see Titz and Karbach 2014, for a review). Findings of children and adults combined, however, do not show transfer effects to either reading or mathematical abilities (Melby-Lervåg and Hulme 2013; Schwaighofer et al. 2015). Future meta-analyses including only children have to decide whether this transfer effect might be only valid for children who are still developing their reading skills.

Moderating Variables. The current controversy about the existence of far transfer effects demonstrates the importance of considering moderating variables in evaluating training and transfer effects. Possible moderating variables are training-specific features (e.g., type, intensity, and duration of training; see von Bastian and Oberauer 2014, for a review), individual differences (e.g., baseline performance, age, personality; see Katz et al. this volume, for a review), and within-person processes during training (e.g., the strength of the relation between daily motivation and WM performance; Könen and Karbach 2015). As elaborate reviews on these issues do already exist (see above), we do not repeat their empirical findings here. We are, however, strongly convinced that the failure to consider moderating variables—not only in meta-analyses but also in primary studies—could mask training and transfer effects.

Maintenance. The longevity of training-induced benefits is a key aspect of the value of WM interventions. Near transfer effects appear to be mostly stable, which is even acknowledged by generally critical reviews (e.g., Shipstead et al. 2012). A recent meta-analyses on studies with children and adults provided valuable evidence as it included 42 immediate effect sizes of near transfer to verbal WM and 11 long-term effect sizes derived from follow-up tests conducted on average eight months after the posttests. After the removal of outliers, immediate near transfer effect sizes were moderate (Hedges's $g=0.3$–0.6), and long-term effect sizes were small to moderate (Hedges's $g=0.2$–0.4). The meta-analyses further demonstrated comparable immediate and long-term effects for visuospatial WM, albeit based on fewer effect sizes (Schwaighofer et al. 2015). Thus, even several months after WM training, near transfer effects to other WM tasks are still valid.

The longevity of far transfer effects, however, is strongly discussed. Important evidence comes from the COGITO study (Schmiedek et al. 2014), in which a sample of younger adults practiced 12 tests of perceptual speed, WM, and episodic memory for over 100 daily 1-h sessions. The findings demonstrated a net far transfer effect of .23 to a *latent factor* of reasoning 2 years later (compared to a passive control group), which did not differ in size from the immediate effect 2 years earlier. This shows that intensive cognitive training interventions can have long-term broad transfer at the level of cognitive abilities. However, as this was a multi-domain training, the contribution of the WM training component cannot be isolated. This is essential, since a recent meta-analysis on single-domain WM training studies provided no evidence for the longevity of far transfer effects (Schwaighofer et al. 2015).

Neuropsychological and Everyday Correlates. Identifying correlates to both neural functions and behavior in everyday life is another key aspect when assessing the value of WM interventions. A couple of neuroimaging studies provided first evidence that training-induced increases of WM performance were related to changes within a network of brain regions generally known for its association with WM functioning (i.e., dorsolateral prefrontal cortex, posterior parietal cortex, and basal ganglia; see Morrison and Chein 2011, for a review). Training-induced transfer was related to changes within networks of brain regions associated with performance on both the training and transfer tasks (cf. Morrison and Chein 2011). This could indicate that far transfer is more likely if the training and transfer tasks engage specific overlapping neural processing mechanisms and brain regions (Dahlin et al. 2008).

Correlates to behavior in everyday life are mostly tested in the context of ADHD symptoms. A recent meta-analysis integrated 13 effect sizes of studies with children and adults and indicated a moderate training-induced decrease of inattention in daily life ($d = -0.5$). Seven effect sizes from follow-up tests conducted 2–8 months after the posttests suggested persisting training benefits for inattention ($d = -0.3$; Spencer-Smith and Klingberg 2015). Thus, benefits of WM training might generalize to improvements in everyday functioning.

Current Discussion

As the findings on far transfer reviewed above already indicated, the field is currently in the middle of a huge controversy on the effectiveness of WM training. Many arguments apply to cognitive training in general but are largely discussed in the context of WM training. We briefly review three main discussion points (see Schmiedek this volume for more details).

Adequate Control Groups. A major concern in the field of WM training is the appropriateness of the control condition(s). The field fundamentally agrees on the advantages of active control groups and the necessity of considering the type of control group in interpreting findings (passive control groups receive no treatment, and active control groups receive a treatment that does not qualify as WM training). The type of control group is a standard moderator tested in meta-analyses and topic of several reviews (e.g., Green et al. 2014). The field does, however, disagree on the potential benefit of passive control conditions. Some emphasize the risks of overestimating training and transfer effects and false claims of causality in passive control designs (they cannot control for expectancy and other non-focal effects, e.g., Melby-Lervåg and Hulme 2016). Others in turn emphasize the difficulty of finding an adequate active control condition, which produces the same non-focal effects (e.g., which is motivating and challenging) but does not draw on WM (cf. Oberauer 2015). If the active control condition does draw significantly on WM, an underestimation of training and transfer effects is likely. A self-evident consequence of all risks would be to include both passive and active control groups and assess motivation and expectancy in active control groups.

Underpowered Studies. Underpowered studies with too few participants per training group are a common problem in the field. Naturally, null findings in underpowered studies should not be interpreted, but underpowered studies can theoretically produce spurious significant effects, too. Meta-analytic procedures typically adjust effect sizes for the sample sizes of the included studies, but the estimates can still be affected. The only solution for this issue would be a more consequent peer-review system requesting power estimates. A couple of notable exceptions exist, for example, a study on a multi-domain online training (including WM training) with $N = 4715$ participants. It demonstrated moderate transfer effects to several cognitive functions such as WM and reasoning compared to an active control condition (Hardy et al. 2015).

Research Bias. It is obvious that the present research labs fundamentally differ in whether they have an optimistic or pessimistic view on WM training outcomes, particularly on far transfer. This could be very valuable because it could be the foundation of a fruitful discussion. However, the current debate is far too heated, which could—in the worst case—result in biased research. That is, it could result in a biased publication of one's own work and a biased reading of other work. In our view, three things are helpful to address this issue: (1) consideration of labs/authors as moderating factor in meta-analyses (e.g., in Au et al. 2015), (2) reports of Bayesian analyses which allow for quantifying the strength of evidence in favor of both the null and the alternative hypothesis (e.g., Dougherty et al. 2016), and (3) endorsement of a more differentiated perspective and language through senior researchers (e.g., Oberauer 2015) and peer review. Taken together, the necessary tools to overcome research bias already exist and should be applied.

Conclusion

In summary, consistent evidence suggests significant average training effects and significant near transfer to non-trained WM tasks. However, evidence for far transfer to other cognitive functions is mixed, which caused a vivid controversy in the field. Still, the prospect of successful WM training has so many significant theoretical and practical outcomes that we should be more than motivated to investigate conflicting findings. If the existing evidence for transfer could be further validated, it would significantly impact our theoretical understanding of both WM and the transfer constructs (e.g., in terms of plasticity). It could also positively impact intervention programs, where even small gains in WM capacity and transfer constructs could actually make a difference relevant to everyday life (e.g., for school children relying on WM capacity to improve learning processes). Further, the large individual differences in training outcomes (Katz et al. this volume) should also motivate us to understand these differences. We agree with Colzato and Hommel (this volume) that the current controversy about the effectiveness of training is likely partly due to the failure to consider individual differences. Not considering the personality of the trained participants, their experiences, and their life contexts during training could mask training effects. We should not only ask whether WM training works on average but also for whom it works and in which contexts and situations it works.

References

Au, J., Buschkuehl, M., Duncan, G. J., & Jaeggi, S. M. (2016). There is no convincing evidence that working memory training is NOT effective: A reply to Melby-Lervåg and Hulme (2015). *Psychonomic Bulletin and Review, 23*, 331–337.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: A meta-analysis. *Psychonomic Bulletin & Review, 22*, 366–377.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*, 1–29.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*, 485–493.

Barrett, L. F., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin, 130*, 553–573.

Bürki, C., Ludwig, C., Chicherio, C., & de Ribaupierre, A. (2014). Individual differences in cognitive plasticity: An investigation of training curves in younger and older adults. *Psychological Research, 78*, 821–835.

Buschkuehl, M., Jaeggi, S., Kobel, A., & Perrig, W. J. (2008). *Braintwister: Aufgabensammlung für kognitives Training [Braintwister: Tasks for cognitive training]*. Bern: Universität Bern, Institut für Psychologie.

Dahlin, E., Neely, A., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science, 320*, 1510–1512.

Dougherty, M. R., Hamovitz, T., & Tidwell, J. W. (2016). Reevaluating the effectiveness of n-back training on transfer through the Bayesian lens: Support for the null. *Psychonomic Bulletin and Review, 23*, 306–316.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*, 756–772.

Hardy, J. L., Nelso, R. A., Thomason, M. E., Sternberg, D. A., Katovich, K., Farzin, F., et al. (2015). Enhancing cognitive abilities with comprehensive training: A large, online, randomized, active-controlled trial. *PLoS One, 10*, e0134467.

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory, 18*, 394–412.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. E. (2004). The generality of working-memory capacity: A latent-variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*, 189–217.

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*, 2027–2037.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences, 14*, 317–324.

Könen, T., & Karbach, J. (2015). The benefits of looking at intraindividual dynamics in cognitive training data. *Frontiers in Psychology, 6*, 615.

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136*, 659–676.

Melby-Lervåg, M., & Hulme, C. (2013). Is working-memory training effective? A meta-analytic review. *Developmental Psychology, 49*, 270–291.

Melby-Lervåg, M., & Hulme, C. (2016). There is no convincing evidence that working memory training is effective: A reply to Au et al. (2014) and Karbach and Verhaeghen (2014). *Psychonomic Bulletin and Review, 23*, 324–330.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wagner, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Morrison, A., & Chein, J. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review, 18*, 46–60.

Oberauer, K. (2009). Design for a working memory. *Psychology of Learning and Motivation, 51*, 45–100.

Oberauer, K. (2015). *Training of intelligence: A question of intelligent training*. Retrieved from May3,2016,http://www.psychonomic.org/featured-content-detail/training-of-intelligence-question-of-intelligent-t

Salminen, T., Strobach, T., & Schubert, T. (2012). On the impacts of working memory training on executive functioning. *Frontiers in Human Neuroscience, 6*, 166.

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2014). Younger adults show long-term effects of cognitive training on broad cognitive abilities over 2 years. *Developmental Psychology, 50*, 2304–2310.

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist, 50*, 138–166.

Shinaver, C. S., Entwistle, P. C., & Söderqvist, S. (2014). Cogmed WM training: Reviewing the reviews. *Applied Neuropsychology: Child, 3*, 163–172.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin, 138*, 628–654.

Spencer-Smith, M., & Klingberg, T. (2015). Benefits of a working memory training program for inattention in daily life: A systematic review and meta-analysis. *PLoS One, 10*, e0119522.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research, 78*, 852–868.

von Bastian, C. C., Locher, A., & Ruflin, M. (2013). Tatool: A Java-based open-source programming framework for psychological studies. *Behavior Research Methods, 45*, 108–115.

von Bastian, C. C., & Oberauer, K. (2013). Distinct transfer effects of training different facets of working memory capacity. *Journal of Memory and Language, 69*, 36–58.

von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: A review. *Psychological Research, 78*, 803–820.

Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory, and how can we measure it? *Frontiers in Psychology, 4*, 433.

Episodic Memory

Elisabeth Wenger and Yee Lee Shing

Introduction

Episodic memory circumscribes the ability to remember events, occurrences, and situations embedded in their temporal and spatial context—in other words, the memory of "what," "where," and "when" (Tulving 2002). It is the unique ability of humans to travel back in time and re-experience past events. To achieve this, elements belonging to the same event need to be associated with each other while being separated from other elements belonging to other events (Tulving 2002).

Throughout the lifespan, episodic memory functioning continuously undergoes extensive change, with rapid increases during childhood, decreases in adulthood, and accelerated decline in very old age (Shing et al. 2010). Given the important role that episodic memory plays in our daily lives, the prospect of potential trainability of episodic memory is a highly attractive idea. This applies to younger adults hoping to optimize their episodic memory ability, but probably even more to older adults, who generally experience a profound decline in episodic memory functioning that can seriously affect their well-being and quality of life. Therefore, it makes sense to incorporate studies of older adults into our consideration of episodic memory and training. In the following, we first provide a brief account of the definition and processes that are involved in episodic memory. We then discuss two theoretical frameworks, one concerning the components of episodic memory across the lifespan

---

E. Wenger (✉)
Center for Lifespan Psychology, Max Planck Institute for Human Development,
Berlin, Germany
e-mail: wenger@mpib-berlin.mpg.de

Y.L. Shing
Center for Lifespan Psychology, Max Planck Institute for Human Development,
Berlin, Germany

Division of Psychology, University of Stirling, Stirling, UK
e-mail: yshing@mpib-berlin.mpg.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_7

and the other concerning the conception of plasticity. These theoretical frameworks help to guide us through the large body of memory training literature. We then summarize and integrate the behavioral literature on memory training and aging, followed by the more recent neuroimaging literature on the topic. Building upon some key points extracted from these sets of literature, we finally discuss the utility of multifactorial types of memory training and potential future work in this direction.

Episodic Memory: Definition and Processes

Following Squire's taxonomy of memory (Squire 1986), long-term memory can be divided into two profoundly different parts: declarative memory and nondeclarative memory. Nondeclarative memory refers to information that is difficult to articulate and does not require conscious awareness. Traditionally, it is thought to comprise procedural memory, classical conditioning, and priming. Declarative memory as our capacity to recollect events and facts, on the other hand, is the umbrella term for both episodic memory and semantic memory. Semantic memories are generalized and encyclopedic and not tied to a specific time or place. In contrast, episodic memories refer to specific episodes or events in a person's life. These memories are tied to the time and place in which the information was acquired. It follows that episodic memory, as a form of explicit memory, involves encoding, consolidation, and retrieval of events. When new declarative information is processed by the brain, it is presumed to be *encoded* by the medial temporal lobe (MTL) and then preserved in different cortical parts in the brain (Paller and Wagner 2002). The *consolidation* of memory traces is a process that stabilizes memory traces so they are preserved and typically takes place during post-learning periods when the brain is not consciously encoding or retrieving a certain memory (McGaugh 2000). *Memory retrieval* is assumed to approximate encoding processes in terms of activated brain regions (Nyberg et al. 2000) and is generally found to be dependent on the MTL as well as prefrontal cortex (PFC).

Two-Component Framework of Episodic Memory

We introduce the two-component framework of lifespan episodic memory here because, as we will demonstrate, the framework helps to orient and organize predictions as well as findings from the large body of literature on memory aging and plasticity. It has been proposed that episodic memory embodies two interacting components:

1. The *strategic* component refers to control processes that assist and coordinate memory processes at both encoding and retrieval. These processes may include elaboration and organization of memory content at encoding and specification,

verification, monitoring, and evaluation of relevant information at retrieval (e.g., Simons and Spiers 2003). On the neural level, the strategic component relies mostly on regions in the PFC and parietal lobes.
2. The *associative* component, on the other hand, refers to mechanisms of binding together different features of a memory item, different memory items, or a given memory episode and its context, into coherent representations, and is mediated by areas of the MTL.

Several behavioral experiments have indicated that these two components develop independently across the lifespan (Brehmer et al. 2007). In short, the associative component has been found to be relatively functional by middle childhood, but exhibits age-related decline in older adults. In contrast, the strategic component has been found to function at a level below that of young adults in children and older adults, most likely due to protracted maturation of PFC regions (and to some extent, of parietal regions as well) across childhood and early age-related decline in PFC regions across later part of adulthood (Shing et al. 2010).

The Concept of Plasticity

Research has shown that the persistent view of an adult brain incapable of change is too pessimistic: the brain remains flexible throughout the lifespan and can adjust to new experiences and challenges, albeit to varying degrees (for a review, see Lövdén et al. 2013). In the conception that we subscribe to, plasticity denotes the capacity for change in brain structure induced by a mismatch between the demands of the environment and the current functional supply the brain can momentarily offer (Lövdén et al. 2010). If the system is capable of a response to altered requirements through previously existing flexibility alone, then no mismatch is experienced, and no plastic change is necessary. On the other hand, if the mismatch is too large, that is, if new requirements are far too high for the momentary functional level of the brain, the system will not be able to assimilate in any way, and plastic changes will also not evolve. In other words, this model emphasizes that the system needs to experience mismatch, which means that the new environmental requirements need to lie between certain boundaries of task difficulty being too high and too low in order to evince experience-dependent plastic changes. Such changes can then help the system to adapt to new circumstances.

Plasticity in Episodic Memory

Behavioral Evidence Demonstrating Plasticity Throughout the Lifespan. Training programs designed to enhance memory performance have proliferated over the past decades, and meta-analytic reviews support the efficacy of at least some of these types of memory training across a broad array of memory tasks (Lustig et al. 2009; Verhaeghen et al. 1992). Episodic memory can be trained by instructing people to use a specific strategy, such as the Method of Loci, name–face mnemonics, number mnemonics, or story and sentence mnemonics, strategies altering the organization of material (categorization, chunking, associations, imagery) or optimizing basic processes like rehearsal or concentration, or even strategies making the best use of external memory cues (for a review, see Gross et al. 2012). In contrast to attempts to train episodic memory via strategy instruction, there have also been endeavors to target the process of memory without strategy instruction, for example, via recollection training (Jennings and Jacoby 2003). In this study, participants were given several trials of a continuous recognition task in which they had to use recollection to identify repeated items. After each trial, the number of intervening items between repetitions increased gradually. This incremented-difficulty approach has been shown to enhance the ability to recollect information across increasing delay intervals and has also been replicated and shown to generalize to at least some working memory tasks. Thus far, a variety of training routes have been shown to improve episodic memory performance in younger as well as older adults.

The next question is whether there are age-related differences in the efficacy of memory training and to which extent memory training may help older adults to reduce age deficits in memory performance. Importantly, cognitively healthy older adults are able to acquire and utilize memory strategies, even up to their 80s and can indeed improve their memory performance through this form of contextual support (for a review, see Brehmer et al. 2014). Older adults often show much improvement in memory performance, bringing them to the initial level of performance of younger adults before training. However, in terms of plasticity, younger adults seem to profit more from strategy-based memory-enhancing interventions than older adults do (e.g., Brehmer et al. 2007; see also Guye et al. this volume). This is clearly visible in the so-called testing-the-limits approach: after extensive training in serial recall word lists with the Method of Loci[1] (i.e., after 17 training sessions distributed over the course of more than 1 year), there is an almost perfect separation of age groups—a magnification of age differences in performance after training (Baltes and Kliegl 1992). Thus, while older adults can clearly benefit from strategy-based memory training, sometimes approaching or even reaching the initial performance level of younger adults, they do not benefit as much as younger adults do, leading to a magnification of age differences after training (see Fig. 1).

There may be several reasons for the above findings. For one, older adults may have difficulties in forming novel associations between landmarks and the to-be-remembered information, for example, due to age-related decline in MTL regions, which are known to be crucial for associative memory formation. They may also have difficulties in the use of mental imagination for memorization and find it

---

[1] In the Method of Loci, participants are presented with lists of words, which are learned by forming visual associations between the *n*th word and the *n*th place (locus) of a fixed trajectory of places (loci) scanned mentally by the participant. Retrieval occurs by taking a mental walk along the trajectory, retrieving the associated image at each locus, and deriving the original word from it.

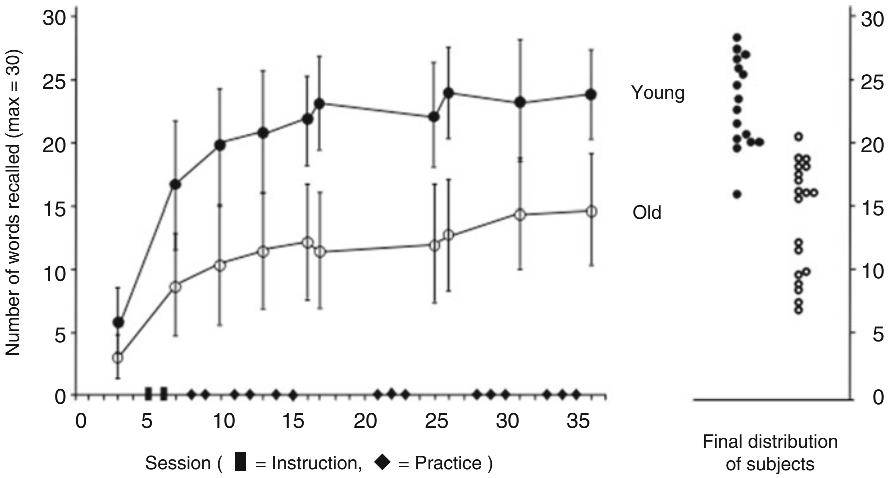

Fig. 1 Training effects and magnification of age differences. Older adults can benefit from memory training, thereby reaching initial performance levels of younger adults. However, younger adults benefit even more, leading to a magnification of age differences after training (Adapted from Baltes and Kliegl 1992)

difficult to form bizarre or unnatural images, which is important for the efficacy of the Method of Loci. Both of these explanations would add up to being a barrier when using rather than acquiring the mnemonic. Age differences in compliance regarding the use of the taught strategy may also play a role. In addition, all of the variables associated with learning in old age (e.g., the speed of mental operations) are characterized by large age differences favoring the young. Age differences in episodic memory performance could then be magnified by training (as in an amplification model) partly because the abilities associated with plasticity are reduced with advancing age (Verhaeghen and Marcoen 1996). While between-person and therefore age differences can be reduced after initial mnemonic instruction (i.e., compensation), age differences are magnified after extensive adaptive practice because baseline performance and general cognitive resources correlate positively with training gains, leading to reduced memory plasticity in older adults (Lövdén et al. 2012).

It is interesting to note that children's episodic memory performance can also be improved through instruction and practice and even more so than older adults: children can advance to the trained level of young adults when they have the chance to practice the newly learned strategy extensively (Brehmer et al. 2007). In this case, instruction gains may primarily reflect developmental and individual differences in the strategic component of memory—that is, the current ability of individuals to make use of the newly learned mnemonic strategy to actively organize (or categorize) the to-be-remembered material. Practice gains on the other hand, which are much stronger in children than in older adults, may then reflect developmental and individual differences in the associative component of episodic memory more than differences in the strategic component—that is, individuals' latent potential in fine-tuning mechanisms involved in the execution of the mnemonic strategy to optimize the formation and retrieval of new associations. Taken together, this evidence reveals that while both children and older adults benefit from memory strategy instruction, only children can improve significantly more through extensive training and practice because they can rely upon the associative component of memory, which is relatively mature. Older adults, on the other hand, show deterioration in the associative component such that even after the strategic deficit has been reduced by strategy instruction, they are limited in their memory improvement.

Training-Related Changes on the Neural Level. Given the improvement in behavioral performance, it is unsurprising that some studies (mostly employing the Method of Loci training) have found associated change in brain activation. A comparison of encoding before and after instruction revealed increased activity in frontal areas and fusiform gyrus, and recall after instruction additionally showed significant activation in parahippocampal gyrus and parietal regions as compared to recall before instruction (Kondo et al. 2005). Maguire and colleagues investigated superior memorizers in contrast to control subjects and found increased activation during encoding in very similar regions, namely, medial parietal cortex, retrosplenial cortex, and right posterior hippocampus (Maguire et al. 2003). Importantly, nearly all of the superior memorizers in this study happened to use a spatial learning strategy like the Method of Loci. In general, the activation of frontal regions in these studies underlines the increased engagement of control processes and thus the strategic component, with more posterior, parietal activation pointing to the specific involvement of imagery due to the nature of the training, while activation in temporal lobe indicates increased engagement of the associative component.

In the context of an aging study, Nyberg and colleagues demonstrated increased activity during memory encoding in occipital-parietal and frontal brain regions after learning the Method of Loci in young adults. Older adults did not show increased frontal activity, and only those older participants who had benefited from the mnemonic exhibited increased occipital-parietal activity (Nyberg et al. 2003). Therefore, age-related differences in memory plasticity may reflect both a frontal processing deficiency (diminished processing resources) and a posterior production deficiency. Interestingly, a study focusing on encoding success (i.e., successful memory formation) instead of encoding processes generally, regardless of outcome (as in the case of Nyberg et al. 2003), found no age differences in neural activation but rather comparable training-induced activation changes across the lifespan (Brehmer et al. 2015). This might speak to the proposition that brain areas supporting successful memory encoding following strategy instruction and practice remain quite stable across the lifespan, particularly in those older adults that have more youth-like brains, such as the positively selected study sample in the Brehmer et al. study (brain maintenance hypothesis of cognitive aging; Nyberg et al. 2012; see also Schmiedek this volume).

Instructions for the use of a new strategy to improve episodic memory performance can be viewed as a case study for the plasticity model introduced above (Lövdén et al. 2010, 2013). Can we regard functional changes as evidence for plasticity when participants show improved performance after instruction for strategy use? Following the theoretical definition laid out above, a more or less immediate change in behavioral performance and its accompanying change in functional activation due to strategy instruction would not be considered as manifested plasticity but rather as flexibility. In the words of Paul Baltes, this improvement following instruction could be termed *baseline reserve capacity*, namely, what an individual is capable of when the conditions of assessment are optimized, in other words, providing for an extended range of possible performances with additional resources (Baltes 1987). *Developmental reserve capacity*, on the other hand, would then be the plasticity as defined in our theoretical model above, namely, a further extension of performance range after conditions have been altered, with the aim of full activation, and possibly expansion, of an individual's task-relevant cognitive or neural resources. The strongest evidence for such developmental reserve capacity or plasticity would then be given if memory performance as such *generally* improved after strategy training, even if the newly acquired strategy was not used at this specific moment. Theoretically, the extensive use of such a mnemonic technique as the Method of Loci may enable an aged individual to rechallenge brain regions important for episodic memory tasks that have become under-challenged due to age-related decline. The heightened recruitment and engagement of these brain regions may then evoke macroscopic changes in brain structure—hence, manifestations of plasticity.

Combination of Training Types to Enhance Generalizability and Maintenance. In general, it seems to be beneficial, if not necessary, for the enhanced magnitude and preservation of behavioral effects to combine training of mnemonic techniques with other important factors affecting memory performance. A crucial limitation of targeted training interventions has been the widespread inability to sustain and generalize (i.e., transfer) the benefits of training in a specific strategy beyond the tasks actually used for training (Noack et al. 2014; see Schmiedek this volume). The most promising results have been provided by multifactorial interventions, in which different memory-enhancing techniques were combined with training of other skills (e.g., attention, relaxation; see Verhaeghen this volume). Under these circumstances, memory performance can improve and can be sustained for up to 3.5 years (Stigsdotter Neely and Bäckman 1993). Stigsdotter Neely and Bäckman provide well-founded arguments for the benefit of involving several critical aspects of memory functioning in memory training programs if they are to be maximally effective. Age-related deficits in episodic memory have an array of different sources (Bäckman 1989). Deficient retrieval mechanisms alone or impaired encoding and retrieval mechanisms could just as well play a role as attentional deficits. Older adults also seem to be disadvantaged with respect to a number of noncognitive factors, such as laboratory anxiety and level of arousal. As memory deficits accompanying the aging process have several origins, efforts to alleviate these deficits should ideally be multifactorial as well, to best target the problems (see Colzato and Hommel this volume). Training of encoding operations to provide effective strategies for organization and visualization of the material could then be combined with training of attentional skills—to improve concentration, focusing of attention, and vigilance, all of which are necessary to meet the attentional demands of remembering—and should additionally be combined with training to reduce levels of situational anxiety. Specific pretraining techniques focusing on image elaboration, verbal judgment, and relaxation have also been shown to enhance the application of a mnemonic technique and helped to maintain its efficacy (Sheikh et al. 1986).

Boosting Memory Training: A Promising Future Training Paradigm

Furthermore, reaching beyond the rationale for multifactorial combined training, we would like to emphasize that physical exercise intervention also needs to be taken into consideration (see Pothier and Bherer this volume). In particular, this applies to older adults whose bodily functioning is also undergoing senescent changes that may have strong implications for cognition. Observational studies continue to suggest that adults who engage in physical activity have a reduced risk of cognitive decline and dementia (for a review, see Duzel et al. 2016). Exercise can exert a protective effect, even if initiated in later life. Although the mechanisms through which physical exercise affects cognition, and especially episodic memory, are not yet fully understood, there is growing evidence that selected aspects of cognition are responsive to increases in physical exercise (Cotman and Berchtold 2002). For example, Erickson and colleagues observed that the hippocampus increased in size after 1 year of moderate exercise and this structural change was correlated with changes in spatial memory performance (Erickson et al. 2011; but note that memory changes did not differ between the experimental and the control group). Another study reported selective increases in cerebral blood volume in dentate gyrus—possibly an indicator for exercise-induced neurogenesis—after 3 months of exercising, which correlated with changes in cognitive performance (Pereira et al. 2007). In an earlier study, a combination of mental and physical training led to greater effects on a memory score than either activity alone (Fabre et al. 2002). The mental training program was multifactorial and comprised tasks involving perception, attention, association, and imagination.

Taken together, we propose that future studies should focus on such multidomain training approaches based on findings from the animal literature. Researchers examining rodents have emphasized both cognitive enrichment and enhanced physical activity as the driving forces behind plastic changes (Kempermann et al. 2010). One can speculate that physical activity may not only enhance cognition directly but also improve plasticity as the capacity for change per se. Physical activity may therefore boost the effects of cognitive enrichment or training on both the behavioral and the neural level. Such an additive effect of physical exercise and environmental enrichment has been shown before in the mouse hippocampus (Fabel et al. 2009). Voluntary physical exercise and environmental enrichment both stimulate adult hippocampal neurogenesis in mice, but via different mechanisms. That is, running in a wheel induces precursor cell proliferation, whereas environmental enrichment exerts a survival-promoting effect on newborn cells. Fabel and colleagues reported an increased potential for neurogenesis in that proliferating precursor cells were activated by running and then received a survival-promoting stimulus due to environmental enrichment following the exercise. Ten days of running followed by 35 days of environmental enrichment were additive such that the combined stimulation resulted in a 30 % greater increase in new neurons as compared to either paradigm alone (see Fig. 2; Fabel et al. 2009). Translated to the human

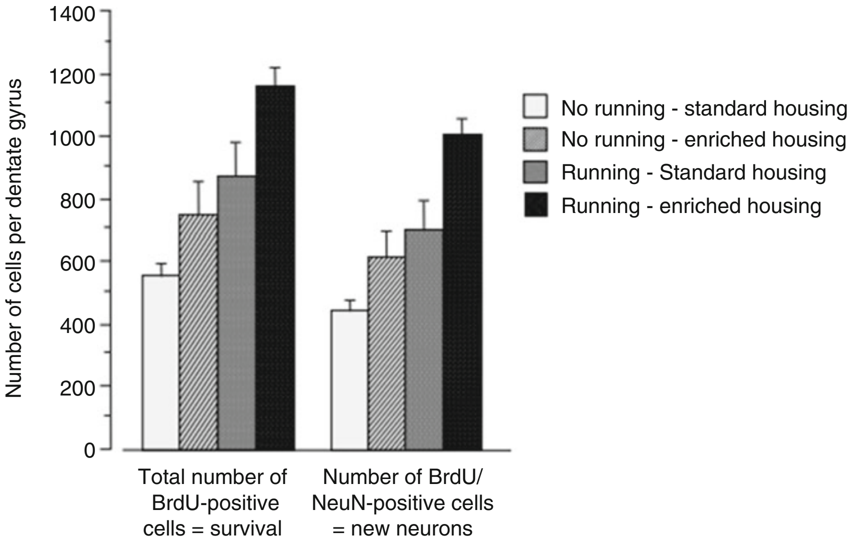

Fig. 2 Additive effect of physical exercise and environmental enrichment in the mouse hippocampus. Voluntary wheel running and enriched housing have each been shown to result in an increased number of cell labels with bromodeoxyuridine (BrdU) and new neurons compared to no running in standard housing. Combined running and enriched housing result in an even greater increase of BrdU-positive cells and newborn neurons. BrdU is commonly used to detect proliferating cells in living tissue (Adapted from Fabel et al. 2009)

hippocampus, this may mean that physical exercise could stimulate proliferating precursor cells that would then be more likely to survive if challenged by appropriate cognitive enrichment relying on the hippocampal structure, as, for example, memory demands. In this way, physical exercise could first "prepare" the aged MTL for increased usage. Hypothetically, any ensuing strategy instruction and specifically the practice of memory strategies could then—and perhaps only then—be successfully and fully exploited. As the associative and strategic components of memory function in intricate ways and are critically important for episodic memory performance, it seems to be a promising route to target both components and the neural regions underlying their functioning, namely, MTL and frontal lobe, in a combined multi-domain training paradigm.

Concluding Remarks

Put simply, episodic memory can be trained. Children as well as younger and older adults profit from strategy instruction, and it is encouraging to see that older adults can reach initial performance levels of younger adults after strategy instruction. Importantly, such performance gains most likely reflect manifestations of flexibility—defined as the adaptive reconfiguration of the exisiting functional and structural repertoire—and, if implemented correctly, rely most heavily on the strategic component of memory, that is, on prefrontal regions of the brain. Further performance gains following extensive practice are then most likely to be manifestations of plasticity. Unlike flexibility, plasticity does not only make use of preexisting neural resources but also changes them fundamentally. Here, older adults show reduced levels of plasticity compared to children and younger adults, as indicated by their lower performance gains following practice. In our view, one promising route for intervention is to provide older adults with memory training in combination with physical exercise to revitalize plasticity and thereby boost training effectiveness. Strategy training alone may be too narrow an intervention to result in substantive transfer and lasting maintenance of acquired skills. Currently, combined memory training types, most promisingly in concert with physical exercise, seem to be the best bet to not only target the strategic but also the associative component of memory, thereby hopefully having a widespread and lasting effect on memory functioning.

References

Bäckman, L. (1989). Varieties of memory compensation by older adults in episodic remembering. In L. W. Poon, D. C. Rubin, & B. A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 509–544). New York: Cambridge University Press.

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology, 23*(5), 611–626. doi:10.1037/0012-1649.23.5.611.

Baltes, P. B., & Kliegl, R. (1992). Further testing of limits of cognitive plasticity: Negative age differences in a mnemonic skill are robust. *Developmental Psychology, 28*(1), 121–125. doi:10.1037/0012-1649.28.1.121.

Brehmer, Y., Kalpouzos, G., Wenger, E., & Lövdén, M. (2014). Plasticity of brain and cognition in older adults. *Psychological Research, 78*(6), 790–802. doi:10.1007/s00426-014-0587-z.

Brehmer, Y., Li, S.-C., Müller, V., von Oertzen, T., & Lindenberger, U. (2007). Memory plasticity across the life span: Uncovering children's latent potential. *Developmental Psychology, 43*(2), 465–478. doi:10.1037/0012-1649.43.2.465.

Brehmer, Y., Shing, Y. L., Heekeren, H. R., Lindenberger, U., & Bäckman, L. (2015). Training-induced changes in subsequent memory effects: No major differences among children, younger adults, and older adults. *NeuroImage, 131*, 214–225. doi:10.1016/j.neuroimage.2015.11.074.

Cotman, C. W., & Berchtold, N. C. (2002). Exercise: A behavioral intervention to enhance brain health and plasticity. *Trends in Neurosciences, 25*(6), 295–301. doi:10.1016/S0166-2236(02)02143-4.

Duzel, E., van Praag, H., & Sendtner, M. (2016). Can physical exercise in old age improve memory and hippocampal function? *Brain, 139*(3), 662–673. doi:10.1093/brain/awv407.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., et al. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences of the United States of America, 108*(7), 3017–3022. doi:10.1073/pnas.1015950108.

Fabel, K., Wolf, S. A., Ehninger, D., Babu, H., Leal-Galicia, P., & Kempermann, G. (2009). Additive effects of physical exercise and environmental enrichment on adult hippocampal neurogenesis in mice. *Frontiers in Neuroscience, 3*, 50. doi:10.3389/neuro.22.002.2009.

Fabre, C., Chamari, K., Mucci, P., Massé-Biron, J., & Préfaut, C. (2002). Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *International Journal of Sports Medicine, 23*(6), 415–421. doi:10.1055/s-2002-33735.

Gross, A. L., Parisi, J. M., Spira, A. P., Kueider, A. M., Ko, J. Y., Saczynski, J. S., et al. (2012). Memory training interventions for older adults: A meta-analysis. *Aging & Mental Health, 16*(6), 722–734. doi:10.1080/13607863.2012.667783.

Jennings, J. M., & Jacoby, L. L. (2003). Improving memory in older adults: Training recollection. *Neuropsychological Rehabilitation, 13*(4), 417–440. doi:10.1080/09602010244000390.

Kempermann, G., Fabel, K., Ehninger, D., Babu, H., Leal-Galicia, P., Garthe, A., & Wolf, S. A. (2010). Why and how physical activity promotes experience-induced brain plasticity. *Frontiers in Neuroscience, 4*, 189. doi:10.3389/fnins.2010.00189.

Kondo, Y., Suzuki, M., Mugikura, S., Abe, N., Takahashi, S., Iijima, T., & Fujii, T. (2005). Changes in brain activation associated with use of a memory strategy: A functional MRI study. *NeuroImage, 24*(4), 1154–1163. doi:10.1016/j.neuroimage.2004.10.033.

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136*(4), 659–676. doi:10.1037/a0020080.

Lövdén, M., Brehmer, Y., Li, S.-C., & Lindenberger, U. (2012). Training-induced compensation versus magnification of individual differences in memory performance. *Frontiers in Human Neuroscience, 6*, 141. doi:10.3389/fnhum.2012.00141.

Lövdén, M., Wenger, E., Mårtensson, J., Lindenberger, U., & Bäckman, L. (2013). Structural brain plasticity in adult learning and development. *Neuroscience and Biobehavioral Reviews, 37*(9B), 2296–2310. doi:10.1016/j.neubiorev.2013.02.014.

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: A review and future directions. *Neuropsychology Review, 19*(4), 504–522. doi:10.1007/s11065-009-9119-9.

Maguire, E. A., Valentine, E. R., Wilding, J. M., & Kapur, N. (2003). Routes to remembering: The brains behind superior memory. *Nature Neuroscience, 6*(1), 90–95. doi:10.1038/nn988.

McGaugh, J. L. (2000). Memory: A century of consolidation. *Science, 287*(5451), 248–251. doi:10.1126/science.287.5451.248.

Noack, H., Lövdén, M., & Schmiedek, F. (2014). On the validity and generality of transfer effects in cognitive training research. *Psychological Research, 78*(6), 773–789. doi:10.1007/s00426-014-0564-6.

Nyberg, L., Habib, R., McIntosh, A. R., & Tulving, E. (2000). Reactivation of encoding-related brain activity during memory retrieval. *Proceedings of the National Academy of Sciences of the United States of America, 97*(20), 11120–11124. doi:10.1073/pnas.97.20.11120.

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences, 16*(5), 292–305. doi:10.1016/j.tics.2012.04.005.

Nyberg, L., Sandblom, J., Jones, S., Neely, A. S., Petersson, K. M., Ingvar, M., & Bäckman, L. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences of the United States of America, 100*(23), 13728–13733. doi:10.1073/pnas.1735487100.

Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *Trends in Cognitive Sciences, 6*(2), 93–102. doi:10.1016/S1364-6613(00)01845-3.

Pereira, A. C., Huddleston, D. E., Brickman, A. M., Sosunov, A. A., Hen, R., McKhann, G. M., et al. (2007). An in vivo correlate of exercise-induced neurogenesis in the adult dentate gyrus. *Proceedings of the National Academy of Sciences of the United States of America, 104*(13), 5638–5643. doi:10.1073/pnas.0611721104.

Sheikh, J. I., Hill, R. D., & Yesavage, J. A. (1986). Long-term efficacy of cognitive training for age-associated memory impairment: A six-month follow-up study. *Developmental Neuropsychology, 2*(4), 413–421. doi:10.1080/87565648609540358.

Shing, Y. L., Werkle-Bergner, M., Brehmer, Y., Müller, V., Li, S.-C., & Lindenberger, U. (2010). Episodic memory across the lifespan: The contributions of associative and strategic components. *Neuroscience & Biobehavioral Reviews, 34*(7), 1080–1091. doi:10.1016/j.neubiorev.2009.11.002.

Simons, J. S., & Spiers, H. J. (2003). Prefrontal and medial temporal lobe interactions in long-term memory. *Nature Reviews. Neuroscience, 4*(8), 637–648. doi:10.1038/nrn1178.

Squire, L. R. (1986). Mechanisms of memory. *Science, 232*(4758), 1612–1619. doi:10.1126/science.3086978.

Stigsdotter Neely, A., & Bäckman, L. (1993). Long-term maintenance of gains from memory training in older adults: Two 3 1/2-year follow-up studies. *Journal of Gerontology, 48*(5), 233–P237. doi:10.1093/geronj/48.5.P233.

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology, 53*, 1–25. doi:10.1146annurev.psych.53.100901.135114.

Verhaeghen, P., & Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: Evidence for an amplification model. *Psychology and Aging, 11*(1), 164–178. doi:10.1037/0882-7974.11.1.164.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging, 7*(2), 242–251. doi:10.1037/0882-7974.7.2.242.

Prospective Memory

Sharda Umanath, Joan Toglia, and Mark A. McDaniel

Introduction

Prospective memory (PM) refers to tasks in which one must remember to carry out an intended action at some point in the future. Good PM is vital in everyday life (McDaniel and Einstein 2007), whether remembering an appointment, paying a bill, or taking a prescription. While PM is important for everyone, the consequences of failure can be much greater for older adults. A missed doctor's appointment or a forgotten pill can have dire repercussions. In addition, older adults complain most about PM failures compared to other memory issues (McDaniel and Einstein), and PM ability declines with age, at least for some types of PM (for a review, see Henry et al. 2004). Given the potential beneficial impact, PM is an ideal target for training, especially in older adults. Yet, very few cognitive training programs in general, or specifically for older adults, have attempted to train PM (see Waldum et al. 2014, for a review). Here, we first discuss the theoretical approach—including *what* to train and *how* to train it—that has guided our attempts to train PM. We then provide evidence from existing data and current preliminary work supporting and informing this approach.

S. Umanath
Department of Psychology, Claremont McKenna College, Claremont, CA, USA
e-mail: sharda.umanath@cmc.edu

J. Toglia
School of Health and Natural Sciences, Mercy College, Dobbs Ferry, New York, NY, USA
e-mail: JToglia@mercy.edu

M.A. McDaniel (✉)
Department of Psychological and Brain Sciences, Washington University in St. Louis,
St. Louis, MO, USA
e-mail: markmcdaniel@wustl.edu

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_8

Theoretical Approach

The fundamental goal in developing a training protocol for PM and a standard goal in cognitive training is to promote transfer or generalization beyond the context of learning. That is, training that learners undergo should be helpful beyond the laboratory and applicable in the real world (see also Guye et al. this volume, Karbach and Kray this volume, Strobach and Schubert this volume, Swaminathan and Schellenberg this volume). However, transfer following cognitive training has been elusive (see Hertzog et al. 2009; McDaniel and Bugg 2012). With this challenge in mind, our broad approach is to look at existing literature and focus on identifying effective PM strategies that learners can be explicitly taught to apply and generalize more broadly. This is a somewhat innovative approach as other cognitive training protocols have embraced different underlying assumptions. For example, some cognitive training has taken a *restorative* approach, attempting to enhance the underlying neural physiology to improve cognition (see Lustig et al. 2009, for a review; Taatgen this volume; Wenger and Shing this volume). Other cognitive training programs include only practice of relevant tasks rather than explicit instruction on how to approach them (e.g., for attentional control, Karbach and Kray 2009; Kramer et al. 1995; Mackay-Brandt 2011; for retrospective memory control, Jennings and Jacoby 2003; for working memory, Harrison et al. 2013; Redick et al. 2013). Even one of the very few training programs aimed at improving PM used only practice and was only somewhat successful in producing transfer (Rose et al. 2015). In contrast, rather than attempting to modify the nervous system or rely on learners gaining spontaneous insights into how to best handle PM tasks through repetitive practice, our approach is to teach effective, efficient strategies with which learners can tackle PM tasks.

We adopted such an approach for several interrelated reasons. First, the PM literature has revealed that dissociated processes underlie different PM tasks (described below), as opposed to perhaps more unitary skills (tasks) that seem to submit to restorative or practice-alone regimens (e.g., attentional control, working memory). Second, PM strategies have been identified that we assume are directly useful in everyday PM tasks (unlike some trained retrospective memory strategies; cf. McDaniel and Bugg 2012). Of note is that PM in the laboratory is quite different than PM in the real world. PM tasks that are encountered in everyday life are widely variable and occur in a myriad of contexts; for example, they include remembering to put a rent check in the mail every month, remembering to pick up a friend at the airport, and remembering to give a housemate a message. By contrast, laboratory PM tasks involve remembering to press a particular key when a given target appears (the word *president* or the syllable *tor*) during an ongoing task (answering trivia questions; Einstein et al. 1995). Thus, a challenge for a PM training program is creating strong connections between the laboratory training context and the situations learners are faced with in their daily lives (see also Guye et al. this volume). Because practice alone can produce brittle skills that are tightly tied to training (e.g., Healy et al. 2005), we felt that appropriately selected strategies and training could better allow learners to link the laboratory context to everyday PM situations.

In fact, Bottiroli et al. (2013) found benefits of a strategy approach for promoting transfer—on retrospective memory tasks—specifically with older adults (see also Wenger and Shing this volume; PRIMs theory in Taatgen this volume). Third, available evidence suggested that these strategies might help override age-related cognitive limitations that attenuate PM performance for older adults (e.g., Liu and Park 2004). In sum, for PM our aim has been to create and test a cognitive training intervention that is applicable for improving PM in the real world and teaches learners effective practical strategies informed by the basic PM literature.

Despite little work on *training* PM, the broader PM literature indicates a number of strategies that learners could use to improve their PM. As just noted, there are different types of PM that rely on different processes (McDaniel and Einstein 2007) and accordingly are associated with different effective strategies. Focal PM tasks involve cues that are presented in the focus of attention and thus are easy to recognize as a cue for performing the related task. For example, seeing a coworker in the hallway can act as a focal cue to give that person a message. In other words, simply seeing that coworker might automatically bring to mind the PM task of relaying the message. Because PM intentions like this are associated with focal cues that can stimulate spontaneous retrieval of the intention, they can be performed without actively looking for the cue. Previous research indicates that creating a strong association between the anticipated cue and the PM intention (an implementation intention strategy) can improve performance on focal tasks (e.g., McDaniel and Scullin 2010).

In contrast, non-focal tasks involve cues that occur outside the focus of attention and are therefore more difficult to notice. For instance, one may need to stop at the grocery store after work, but the store itself is not easy to notice in the midst of a routine drive home where one must pay attention to traffic, etc. Here, actively monitoring for the cue is needed in order to successfully notice (Einstein et al. 2005), otherwise one might drive right by the store. The implementation intention strategy that is effective for focal tasks would not be as helpful in non-focal PM tasks since the key is to notice the cue in the first place (Breneiser 2007). Thus, the best strategy for non-focal tasks may be to simply check for the cue frequently and actively attend to that intention (an event-monitoring strategy; see also Wenger and Shing this volume).

Similarly, time-based PM tasks, wherein an intended action must occur at a particular time, require this type of active monitoring. Furthermore, the only cue is the time itself, whereas in focal and non-focal tasks, events are the cues. This type of task is especially challenging for older adults (Einstein et al. 1995). Prior work indicates that learners who check the clock more often as the target time nears perform intended actions more frequently (Einstein et al.). Consistent with this finding, older adults are less likely than younger adults to ramp up their monitoring as the target time approaches (Einstein et al. 1995; Park et al. 1997). Teaching older adults to use this strategic clock checking may be the most effective strategy for improving their performance on time-based tasks.

Beyond strategies to teach older adults, an important question is how to implement the training. In what form should these strategies be taught such that older adults learn them well and learn to apply them outside the context of learning? Several key factors may be critical for designing the most beneficial training program.

Key Factors for Training: The EXACT Study

As part of a larger cognitive training and aerobic exercise program (EXercise And Cognitive Training project–EXACT; McDaniel et al. 2014), McDaniel and colleagues developed a protocol specifically aimed at improving PM through strategy use (Waldum et al. 2014 describe this protocol in detail; see also Pothier and Bherer this volume). Five main components were implemented in an 8-week intensive intervention. First, learners were given explicit instructions about effective strategies to use in PM tasks, specifically tailored for each type of task. Second, both to increase the generalizability of training and capitalize on previous memory research, the training context varied greatly. In terms of generalizability, as mentioned above, PM tasks are widely variable, both in task type (focal, non-focal, time based) and in context. Accordingly, learners were trained using several ongoing tasks that tapped different types of PM. Encountering various scenarios during training might make learners' approach more flexible and resilient in the face of new PM challenges. Additionally, learners may start to be able to identify the different types of PM tasks and then transfer the appropriate strategies accordingly. This line of reasoning is also consistent with memory research on encoding variability wherein multiple contexts at the learning stage can improve later memory for the to-be-remembered material (Hintzman and Stern 1978).

Third, combined with the wide variety of laboratory tasks, homework was added to the program. That is, learners were given assignments to complete outside the laboratory regarding PM situations they faced in daily life. Explicit practice applying the training they received in the lab to their regular lives is likely to be beneficial for later transfer (e.g., Schmidt et al. 2001). Fourth, as the training program went on, the difficulty of the tasks increased. Learners were asked to keep in mind more PM objectives, and the nature of the tasks also became more challenging. Simultaneously, the trainer's involvement decreased from initially providing explicit strategy instruction prior to each training task to later expecting the learners to use the relevant strategies without prompting. This idea of increasing the difficulty across the training program is consistent with the broader literature on cognitive training. In the restorative approach, the demands of the task are incrementally increased to push the ultimate level of acquisition of the trained skill (e.g., retrospective memory training, Jennings and Jacoby 2003; attentional training, Mackay-Brandt 2011). Additionally, in the occupational therapy domain, strategies are trained such that learners are required to initiate and apply the strategies across activities that systematically differ in physical similarity and context but remain at the same level of complexity. In this sideways approach, task difficulty is only increased after strategy transfer has been observed (Toglia 2011). Again, intervention is designed to encourage transfer and generalize the training to learners' everyday lives.

Fifth, a key component of the EXACT project was to evaluate the training effects with computer simulations of cognitively challenging real-world tasks (e.g., cooking breakfast, Craik and Bialystok 2006; remembering health-related information and the sources of that information). Older adults completed (pre- and post-training) a simulation of going through the course of a day for three successive days (the Virtual Week (VW) task; Rose et al. 2010). During the course of each day, the older adults have to remember a number of prospective tasks, such as "remember to drop off dry cleaning when you go shopping" and "remember to take asthma medication at 11 a.m. and 9 p.m." (in the game, a person's token passes squares that indicate the virtual time for the day).

The results of the EXACT study were especially encouraging with regard to training PM (see McDaniel et al. 2014). Eight weeks of cognitive training on laboratory PM tasks with the components discussed above produced significant gains (from pre- to posttests) in remembering to perform the real-world VW PM tasks relative to a control that did not receive PM training or an aerobic exercise control (a real clock time-based task did not show training effects). By contrast, cognitive training did not produce significant gains for the cooking breakfast or memory for health information tasks. However, the EXACT study was not designed to isolate the impact of particular training components to the success of the training protocol for improving PM; accordingly, many basic issues remain unanswered (see Waldum et al. 2014, for detailed discussion).

Briefly, the cognitive training included attentional control training tasks and retrospective training tasks in addition to PM training; thus, though plausible, it remains uncertain that the PM training alone would be sufficient to produce transfer to the real world like VW tasks. Also, the PM training protocol included a number of components—including using a different laboratory task each week (variable training) and explicit strategy instruction—either or both theoretically could have been instrumental in promoting transfer. Initial support for the value of these components comes from noting that in the EXACT protocol, the attentional control training and the retrospective memory training, following the precedent from the literature, generally did not include explicit strategy instruction and repeatedly used the same training task over the course of the eight weeks. As just mentioned, there was no significant transfer of training to the real-world attentional control task (cooking breakfast) or to the real-world retrospective memory task (memory for health information). Clearly, experiments that directly compare variable training (varying the parameters of the practice task rather than keeping it constant; e.g., Kerr and Booth 1978; Goode et al. 2008) to training with a single task and directly compare explicit strategy instruction with a typical practice-only procedure (e.g., Kramer et al. 1995; Jennings and Jacoby 2003) would provide valuable insights as to the importance of these factors in promoting the generalizability of cognitive training. In the next section, we describe our ongoing research doing just that in PM training.

Finally, a feature of the EXACT project that poses practical limitations is that the cognitive training was a huge undertaking, requiring a great deal of commitment and investment from the trainers and the learners. A major practical issue is whether a more efficient training program focusing on PM per se and restricting training to one session (rather than multiple sessions as in EXACT) could support transfer of strategies to real-world PM tasks. Initial studies have reported significant improvements with older adults in everyday-like PM tasks using a brief implementation intention instruction for the target PM task (Liu and Park 2004; Shelton et al. 2016). Accordingly, it seemed possible that a single PM strategy training session could support transfer, and if so, then an efficient and nondemanding training protocol could be provided to older adults to improve their everyday PM success.

Ongoing Research

Our ongoing research aims to address the questions raised above. Specifically, our focus is on evaluating the success of PM training within a single 60–90 min training session that uses variable training tasks versus a single training task and that uses explicit strategy instruction versus practice alone. At present, we have completed testing on only a handful of participants (up to three in each condition of four conditions defined by the factorial combination of strategy instruction versus practice alone and variable versus a single training task). Overall, for the transfer task (Virtual Week), those who trained with variable training tasks and received explicit strategy instruction showed the most improvement in performance (19 % improvement from pretest to posttest compared to an average of just 10 % across all other conditions). We caution that these data simply show some initial trends that may hint at what aspects of training are the most beneficial for improving prospective memory in older adults.

Metacognitive Strategy Training

It may be that neither explicit strategy instruction nor practice alone (such that learners might not discover their own strategies) is most optimal. Instead, guided use of effective strategies that integrates metacognitive components may extend benefits of strategy training by helping a person recognize when and why a particular strategy is applicable and thus increase probability of generalization. Metacognitive strategy training focuses on the general process of how to go about a task, including analyzing task demands, strategy generation and selection, and self-monitoring and self-evaluation of performance (Toglia 2011). A learner-centered approach that actively engages the participant in a collaborative process of planning or choosing strategies and evaluating effectiveness can be integrated with metacognitive strategy training by using systematic questions and guided prompts to facilitate self-generation of strategies (Polatajko et al. 2011; Toglia 2011). Learner-centered approaches, such as guided discovery, are rooted in constructivism theories of learning that suggest that learning is enhanced when the learner is actively engaged in the process of discovering solutions themselves.

Preliminary evidence supporting use of guided metacognitive strategy techniques in enhancing transfer of learning or generalization has been reported for older adults (Bottiroli et al. 2013; Dawson et al. 2013) as well as for cognitive rehabilitation of executive functions in individuals with stroke or brain injury (Skidmore et al. 2014; Toglia et al. 2010). For example, Bottiroli et al. (2013) found that transfer of learning was facilitated in older adults by encouraging active involvement in analyzing memory tasks involving lists, stories, locations, or paired associates and adapting strategies to meet task demands. Guided metacognitive strategy training, however, has not been applied to PM training. Another important question therefore is whether PM

Table 1 Guided metacognitive strategy framework for prospective memory training

Treatment session components		Metacognitive focus
Pre-activity discussion	Identify type of PM	Analysis of task demands
	Identify everyday activities that involve similar PM requirements	Connect PM task with everyday activities. Identify similarities of task characteristics
	Generate strategies for PM	Plan and choose strategies that match task demands
During task	Stop and mediate after errors are observed	Self-monitoring skills
	Guide generation of alternate strategies if needed	Strategy adjustment based on performance
After task	Participant summarizes methods used and comments on strategy effectiveness	Self-evaluation of performance

strategies are best learned through explicit instruction or through guided metacognitive methods.

We adapted a guided metacognitive strategy framework described by Toglia (2011) to the training of PM. The framework is outlined in Table 1 and consists of three components: (1) pre-activity discussion on analyzing task demands, identifying similarities with meaningful activities, and self- generation of strategies; (2) mediation during the task to facilitate self-monitoring and use of alternative strategies when needed; and (3) after-task questioning aimed at promoting self-evaluation of performance and strategy use. We conducted a pilot pre-post intervention study with 15 healthy older adults, ranging from age 60–90 with a median age of 66, to further develop and test the feasibility and effectiveness of a guided metacognitive strategy approach for PM training. All participants were living independently in the community and scored above the cutoff of 26 on the Montreal Cognitive Screening Assessment. The Virtual Week task (VW task previously described) was used 5–8 days before and after a single guided metacognitive strategy training session to determine whether there was a significant increase in proportion of completed PM tasks following intervention. Participants returned 1 week later for the training session. This session includes three different computerized PM games ("famous faces," "general knowledge trivia", and "Where's Waldo"), previously described by Waldum et al. (2014). The games were counterbalanced and involved different types of PM with increasing difficulty across the tasks (focal + time based, non-focal + time based, a combination of all three or focal, non-focal, and time based).

After a general introduction to types of PM, the participant was then presented with PM trial tasks and asked to identify the type of PM required by the task (focal, non-focal, time based). The trainer followed a script and used systematic questioning to guide the person to the correct response. Next, guided questioning was used to help the person identify how the PM training task was similar to everyday activities or situations. They were then encouraged to identify strategies or the best methods to optimize performance. If the individual was unable to generate strategies

Table 2 Means as a function of type of prospective memory task and time of test, with paired *t*-tests of pre-post differences ($n = 15$)

	Pretest		Posttest		
Outcome	*M*	SD	*M*	SD	*t*
Regular event based	.623	.35	.845	.25	−2.06
Regular time based	.555	.43	.823	.22	−2.92*
Irregular event based	.667	.67	.823	.21	−1.87
Irregular time based	.333	.36	.667	.36	−2.39*

*$p < .01$

with prompts or chose strategies that were judged as inefficient by the examiner, the examiner did not provide comments. Instead the person was given the opportunity to try the activity using their own methods.

During the activity, the examiner stopped and mediated performance as errors occurred and guided the person to reassess the effectiveness of their method. If needed, the person was encouraged to adjust or generate alternative strategies. At the end of the activity, the participant was asked to identify the methods they used to help themselves remember, comment on strategy effectiveness, and whether they would change the way they went about the activity if they did the activity again. One week after training, participants completed 3 days of the VW task and a questionnaire regarding the use of strategies during VW as the final assessment.

Our pilot results show promise for a single-session metacognitive strategy approach. Results of paired sample *t*-tests between pre- and posttest scores for time-based VW tasks revealed significant differences (see Table 2 for means and *t*-values). Event-based tasks demonstrated marginal differences, with *t*-values just below significance levels. This trend is consistent with findings by Waldum et al. (2014), who found a treatment effect for time-based but not event-based PM tasks. Although preliminary findings are encouraging, conclusions cannot be drawn without a control group comparison, which is presently in progress.

Conclusions

All in all, our preliminary results suggest that a relatively brief training session can produce transfer of learned PM strategies to at least a simulation of real-world PM tasks. A unique aspect of our research is the appreciation of different types of PM tasks, with training oriented toward informing learners of these differences and highlighting particular strategies targeted at the different type of tasks. It seems that a parallel approach for retrospective memory training might be considered to improve outcomes for assisting older adults with their everyday retrospective memory challenges (cf. McDaniel and Bugg 2012). Clearly, a definitive conclusion awaits more complete experimental findings, but at this point, we are encouraged that the present training approach might benefit older (and younger) adults in improving their everyday prospective remembering.

More generally, our research is attempting to examine and identify essential ingredients of cognitive training that enhance successful outcomes and generalization. There are many choices to be made in developing cognitive training, and as researchers, we need to be confident that those decisions will provide the greatest improvement (Schmiedek this volume). Fundamentally of interest is what we are trying to train. Many programs have targeted cognitive capacities themselves (see Guye et al. this volume). Instead, our approach is to focus on teaching effective strategies that older adults can use to tackle the PM situations they face.

One concern is how to implement this kind of strategy training, starting with how extensive the training ought to be. Though several sessions may be beneficial, the right kind of single training session may help older adults, which is a more practical proposition. In such a single session, the variability of the tasks that participants are exposed to in training is likely to be critical to later generalizability; experiencing a few different tasks may allow for more robust and flexible strategy development and application. In strategy training, we are also investigating whether explicit strategy instruction or guided metacognitive strategy training might be best. It appears that having such support in instruction does benefit older adults over allowing them to try and develop their own approach to PM tasks (practice alone).

Finally, the ecological validity of the training and the assessments of learning and transfer are critical. PM looks quite different inside and outside the laboratory. Thus, it is an important goal to foster the transfer of effective strategy use from training to the real world. As such, training programs must consider the balance and inclusion of laboratory training, homework, and simulated real-world activities during training such as the VW task. As these different considerations are explored, we are confident that an effective and efficient PM training for older adults will emerge, one that promotes transfer and generalizability to the real-world PM challenges.

Acknowledgments A special thanks is extended to Mercy College Occupational Therapy (OT) students Kim Havel, Mary Tremmel, Teresa Sanchez, and Hasena Punwasie for their assistance with the guided metacognitive strategy pilot project. The authors would also like to thank Deborah Koh for her help with the current prospective memory training work at Washington University. Some of the research discussed was supported by the National Institute on Aging Grant T32 AG000030 awarded to SU.

References

Bottiroli, S., Cavallini, E., Dunlosky, J., Vecchi, T., & Hertzog, C. (2013). The importance of training strategy adaptation: A learner-oriented approach for improving older adults' memory and transfer. *Journal of Experimental Psychology: Applied, 19*, 205–218.

Breneiser, J. (2007). *Implementation intentions and cost in prospective memory retrieval*. Unpublished doctoral dissertation, Washington University.

Craik, F. I. M., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory & Cognition, 34*, 1236–2124.

Dawson, D., Richardson, J., Troyer, A., Binns, M., Clark, A., Polatajko, H., et al. (2014). An occupation-based strategy training approach to managing age-related executive changes: A pilot randomized controlled trial. *Clinical Rehabilitation, 28*, 118–127. doi:10.1177/0269215513492541.

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 996–1007.

Einstein, G. O., McDaniel, M. A., Thomas, R., Mayfield, S., Shank, H., et al. (2005). Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *Journal of Experimental Psychology: General, 134*, 327–342.

Goode, M. K., Geraci, L., & Roediger, H. L. (2008). Superiority of variable to repeated practice in transfer on anagram solution. *Psychonomic Bulletin & Review, 15*, 662–666.

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science, 24*(12), 2409–2419. doi:10.1177/0956797613492984.

Healy, A. F., Wohldmann, E. L., Parker, J. T., & Bourne, L. E. (2005). Skill training, retention, and transfer: The effects of a concurrent secondary task. *Memory & Cognition, 33*(8), 1457–1471.

Henry, J. D., MacLeod, M. S., Phillips, L. H., & Crawford, J. R. (2004). A meta-analytic review of prospective memory and aging. *Psychology and Aging, 19*, 27–39.

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2009). Enrichment effects on adult cognitive development: Can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9*, 1–65.

Hintzman, D. L., & Stern, L. D. (1978). Contextual variability and memory for frequency. *Journal of Experimental Psychology: Human Learning and Memory, 4*, 539–549.

Jennings, J. M., & Jacoby, L. L. (2003). Improving memory in older adults: Training recollection. *Neuropsychological Rehabilitation, 13*, 417–440. doi:10.1080/09602010244000390.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*, 978–990. doi:10.1111/j.1467-7687.2009.00846.x.

Kerr, R., & Booth, B. (1978). Specific and varied practice of a motor skill. *Perceptual and Motor Skills, 46*, 395–401.

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50–76. doi:10.1037/1076-898X.1.1.50.

Liu, L. L., & Park, D. C. (2004). Aging and medical adherence: The use of automatic processes to achieve effortful things. *Psychology and Aging, 19*, 318–325.

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: A review and future directions. *Neuropsychology Review, 19*, 504–522.

MacKay-Brandt, A. (2011). Training attentional control in older adults. *Aging, Neuropsychology, and Cognition, 18*, 432–451.

McDaniel, M. A., Binder, E. F., Bugg, J. M., Waldum, E. R., Dufault, C., Meyer, A., et al. (2014). Effects of cognitive training with and without aerobic exercise in cognitively-demanding everyday activities. *Psychology and Aging, 29*, 717–730.

McDaniel, M. A., & Bugg, J. M. (2012). Memory training interventions: What has been forgotten? *Journal of Applied Research in Memory and Cognition, 1*, 45–50.

McDaniel, M. A., & Einstein, G. O. (2007). *Prospective memory: An overview and synthesis of an emerging field*. Thousand Oaks, CA: Sage.

McDaniel, M. A., & Scullin, M. K. (2010). Implementation intention encoding does not automatize prospective memory responding. *Memory & Cognition, 38*, 221–232.

Park, D., Herzog, C., Kiddor, D., Morrell, R., & Mayhorn, C. (1997). Effect of age on event-based and time-based prospective memory. *Psychology and Aging, 12*, 314–327.

Polatajko, H. J., Mandich, A., & McEwen, S. (2011). The cognitive orientation to daily occupational performance (CO-OP): A cognitive-based intervention for children and adults. In N. Katz (Ed.), *Cognition, occupation and participation across the life span: Neuroscience, neuroreha-*

bilitation and models of intervention in occupational therapy (3rd ed., pp. 299–321). Bethesda, MD: AOTA Press.

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., et al. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General, 142*, 359–379.

Rose, N. S., Rendell, P. G., Hering, A., Kliegel, M., Bidelman, G. M., & Craik, F. I. M. (2015). Cognitive and neural plasticity in older adults' prospective memory following training with the Virtual Week computer game. *Frontiers in Human Neuroscience, 9*, Article 592. doi: 10.3389/fnhum.2015.00592.

Rose, N., Rendell, P. G., McDaniel, M. A., Aberle, I., & Kliegel, M. (2010). Age and individual differences in prospective memory during a "Virtual Week": The roles of working memory, vigilance, task regularity, and cue focality. *Psychology and Aging, 25*, 595–605.

Schmidt, W., Berg, I. J., & Deelman, B. G. (2001). Prospective memory training in older adults. *Educational Gerontology, 27*, 455–478.

Shelton, J. T., Lee, J. H., Scullin, M. K., Rose, N. S., Rendell, P. G., & McDaniel, M. A. (2016). Improving prospective memory in healthy older adults and very mild Alzheimer's Disease patients. *Journal of the American Geriatrics Society, 64*(6), 1307–1312.

Skidmore, E. R., Dawson, D. R., Butters, M. A., Grattan, E. S., Juengst, S. B., Whyte, E. M., et al. (2014). Strategy training shows promise for addressing disability in the first 6 months after stroke. *Neurorehabilitation and Neural Repair, 29*, 668–676. doi:10.1177/1545968314562113.

Toglia, J. P. (2011). The dynamic interactional model of cognition in cognitive rehabilitation. In N. Katz (Ed.), *Cognition, occupation, and participation across the life span: Neuroscience, neurorehabilitation, and models of intervention in occupational therapy* (3rd ed., pp. 161–201). Bethesda, MD: AOTA Press.

Toglia, J., Johnston, M. V., Goverover, Y., & Dain, B. (2010). A multicontext approach to promoting transfer of strategy use and self-regulation after brain injury: An exploratory study. *Brain Injury, 24*(4), 664–677. doi:10.3109/02699051003610474.

Waldum, E. R., Dufault, C., & McDaniel, M. A. (2014). Prospective memory training: Outlining a new approach. Advanced Online Publication *Journal of Applied Gerontology*. doi:10.1177/073346814559418.

Executive Functions

Julia Karbach and Jutta Kray

Introduction

The ability to control behavioral activity and to adapt to changing environmental demands is described as executive functions and includes a set of higher-level cognitive control processes. Many of these control processes gradually develop over childhood and well into adolescence while declining in older age. In this chapter, we will review evidence indicating that executive control functions can be improved by training across a wide range of ages. In the first section, we introduce definitions and models of executive functions and present their implications for the training of executive control. Secondly, we review findings from studies focusing on the training of multitasking, inhibition, and cognitive flexibility and discuss individual differences in the effects of these training interventions. The last section summarizes the current state of research and suggests important issues for future research.

Definition and Models

The term executive functions (EFs) refers to a set of cognitive processes serving to guide thoughts and actions along internal or external goals, tasks, and intentions in order to optimally adapt to changes in the environment. There is relative consensus

---

J. Karbach (✉)
Department of Psychology, Goethe-University Frankfurt, Frankfurt, Germany

Center for Research on Individual Development and Adaptive Education of Children at Risk (IDeA), Frankfurt, Germany
e-mail: karbach@psych.uni-frankfurt.de

J. Kray
Department of Psychology, Saarland University, Saarbrücken, Germany
e-mail: j.kray@mx.uni-saarland.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_9

in the literature what kind of tasks and situations require EF, such as multitasking, task switching and scheduling, and performance monitoring. However, there exist different views on the structure of EF and the question of whether they are better described as a unitary or modular construct. Within traditional models from working-memory research, EF is often conceptualized as a unitary system that is involved in coordinating and controlling of processing and storing of information in working memory. For instance, in the well-known working-memory model by Baddeley (1996), a central executive system is considered to be responsible for coordinating the information flow between the phonological loop, visual–spatial sketchpad, and the episodic buffer. Hence, different functions need to be coordinated such as the active maintenance of task-relevant information, retrieval from long-term memory, attending to relevant information and inhibiting irrelevant ones, and scheduling of multiple tasks. Coming from a neuropsychological research tradition, Norman and Shallice (1986) suggested the supervisory attentional model that distinguishes between automatic and controlled information processing modes by assuming two separate systems, the contention scheduling and the supervisory attentional system (SAS). The SAS is especially required, for instance, in situations in which tasks and demands are novel, difficult, and dangerous or in situations in which the suppressing of a dominant but currently inappropriate behavior and action tendency is needed. Hence, its main function is to bias the contention-scheduling system in a way that task-relevant information is activated while task-irrelevant information is inhibited.

In contrast to the view of a unitary system of EF, other researchers have stressed a modular view assuming a set of several distinct functions. These functions include (a) initiation of complex behavior, (b) actively maintaining of task-relevant information, (c) shifting between tasks and mind sets, (d) planning and scheduling of multiple steps of complex tasks and events, (e) inhibition of inappropriate behavior and response tendencies, (f) performance monitoring and adjustment, and (g) coordination of multiple task requirements, and so on (cf. Miller and Cohen 2001; Smith and Jonides 1999). Such a modular view was further supported by empirical evidence of discrete neuronal systems involved in these different functions that were reported in clinical studies including patients with particular lesions as well as in neuroimaging studies. For instance, it has been found that maintaining and biasing task-relevant task sets during task preparation were specifically associated with activity changes in the dorsolateral prefrontal cortex, while processing of response conflict during task execution was specifically associated with activity in the anterior cingulated cortex (ACC) (Botvinick et al. 2001). Such double dissociations of neuronal activations in different executive functions contributed to a modular view.

Using a structural equation modeling approach, Miyake and colleagues (2000) integrated these opponent theoretical views on EF. They found evidence supporting both the unity and diversity of executive control by investigating individual differences in indicators of three core components of EF, working memory, shifting, and inhibition. Results of this first modeling study revealed that all three constructs were separable but moderately correlated, indicating that they were not fully independent of each other.

Interestingly, this theoretical view is now also supported by meta-analytic evidence on the basis of neuronal data. In this study, Niendam et al. (2012) included about 200 neuroimaging studies on EF examining shifting, planning, working memory, initiation, and vigilance and determined common as well as domain-specific brain activations across these functions. The results indicated a common pattern of activation including the prefrontal, dorsal anterior cingulate, and parietal cortices in line with the idea of the higher-order control system. At the same time, they also found evidence for domain-specific activation depending on the involved executive task in anterior prefrontal, anterior, and midcingulate as well as subcortical brain regions. Note that individual variation in fluid intelligence has been linked to EF and the efficiency of recruiting the dorsolateral prefrontal cortex (e.g., Miller and Cohen 2001).

Implications for the Expected Effects of Executive Function Training

Considering the different theoretical views on EF described above, which positive effects are to be expected after a training of EF? As discussed in detail in this volume (e.g., Schmiedek this volume; Taatgen this volume), a cognitive training intervention should not only result in performance gains on the trained components of EF; it should also generalize to other cognitive functions or even to everyday activities and school and academic performance. Finally, these gains should also persist over longer periods of time. However, if and to what degree transfer of training in cognitive functioning is possible has fueled a heated debate in recent years, especially regarding working-memory training (e.g., Melby-Lervåg and Hulme 2015; Shipstead et al. 2012; see also Katz et al. this volume; Könen et al. this volume).

From the perspective of a unitary view on EF, we would expect to see relatively broad transfer of EF training to a large variety of other aspects of EF because training the higher-order control system should enhance a broad range of different EF. Taking a more modular perspective, the generalization of training gains in one EF should not necessarily result in benefits in another EF, and the scope of transfer should depend on the degree of domain-specific overlap (processing and neural) between the trained and the transfer task (i.e., the more shared resources, the more likely transfer should be). Assuming both common and domain-specific aspects of EF, we would expect to see larger transfer if the prefrontal–dorsal–parietal control network is trained.

Aside from the transfer scope, Lövdén and colleagues (2010) proposed a fundamental precondition for the success of a training intervention in their theoretical framework of cognitive plasticity: They assumed that the environmental demands during training should cause an imbalance with the actual brain supply. In case of a substantial and prolonged mismatch between environmental demands and brain supply, the brain will react to this mismatch with functional or structural brain changes. Taking a lifespan view, age-related deficits in EF that are typically present in childhood and older age suggest that this mismatch will occur more often in these age groups, indicating that especially children and older adults may gain from a moderate mismatch induced by training interventions targeting EF. As a consequence, they will benefit more than younger ones from brain alteration in their less-efficient prefrontal lobe system (see below).

To sum up the theoretical considerations, a training intervention enhancing a superordinate fronto–cingulo–parietal network in groups showing alterations in these brain regions should have a good chance to generalize to other EF and even to fluid abilities. As most of the training studies on EF in the last decade aimed at enhancing working memory/updating and various reviews and meta-analyses exist (see also Könen et al. this volume; Rueda et al. this volume; Guye et al. this volume), we will focus our summary of research findings on recent evidence regarding the effectiveness of training in multitasking, task switching, and inhibition and will discuss them in the light of the theoretical considerations presented above.

Multitasking Training

The majority of multitasking training studies has applied dual-task trainings and reported robust practice-related improvements in the ability to coordinate two simultaneously presented and overlapping component tasks (for a review, see Strobach et al. 2014). These training-induced gains generalized to new, untrained dual-task situations. While no such gains were found after single-task practice (i.e., practice on the component tasks one at a time), hybrid training including both single-task and dual-task situations increased transfer to a visual–auditory dual task (e.g., Liepelt et al. 2011). The second auditory response selection started earlier and more efficiently after hybrid training than after single-task practice, resulting in reduced dual-task costs. This suggests that the training indeed resulted in an optimized and efficient processing of two simultaneously presented tasks.

While these and other findings provided evidence for the acquisition of transferable task-coordination skills, the specific nature of such mechanisms is still under debate. One recent model, the Efficient Task Instantiation (ETI) model (Strobach et al. 2014), assumes that dual-task performance improves after dual-task practice because relevant task information (such as stimulus–response mapping rules) is efficiently and conjointly instantiated in working memory at the onset of a dual-task trial. Several findings from the dual-task literature support the ETI model. First, De Jong (1995) showed that incomplete instantiation of relevant task information resulted in impaired dual-task performance. Second, investigating older adults with age-related working-memory impairments and younger adults without these deficits showed significant age differences: in contrast to younger adults, older participants did not learn the instantiation of a complex second task unless its complexity, and therefore the associated working-memory load, was reduced (Maquestiaux et al. 2004). Third, the efficient instantiation of task information during training was impaired in young adults when a working-memory overload was induced by highly complex training tasks (Ruthruff et al. 2006). These findings are also in line with the theoretical framework outlined above as they underline that training demands have to induce a moderate mismatch that differs across age in order to induce practice-related improvements in EF.

Aside from working-memory processes, the ability to resolve task interference plays an important role for the effectiveness of dual-task training. Evidence for this view comes from a recent study by Anguera and colleagues (2013). They examined the effectiveness of dual-task training in older adults by embedding the training in an adaptively designed game simulation called NeuroRacer. The authors compared training and transfer gains in a group of older adults in three training conditions: participants were (1) to perform both tasks simultaneously (dual-task training condition), (2) to perform each task separately (single-task condition, active control group), or (3) to perform none of the tasks (passive control group). Importantly, the dual-task condition included stimuli that were relevant for both tasks, and participants were to constantly control interference from one task in order to correctly perform the other. Results revealed a larger reduction of dual-task costs under the dual-task training condition than under the active or passive control condition. After 12 h of training, older adults even performed better in this task than untrained younger adults. Moreover, training gains not only generalized to a new, untrained dual task but also to measures of sustained attention and working memory. Importantly, the study also revealed the first robust correlations between behavioral improvement and changes on neural signatures of cognitive control (enhanced midline frontal theta power and frontal–posterior theta coherence).

Task-Switching Training

Most of the studies that aimed at enhancing cognitive functioning by means of a task-switching training have applied a pretest-training-posttest design with one or more treatment groups that practiced to switch between tasks in random or predictable task orders. Active control groups often performed the same tasks but practiced them in separate blocks (i.e., single-task blocks) (see Minear and Shah 2008, who introduced this type of design).

Meanwhile, there is quite a number of training studies that demonstrated robust and substantial improvements in task-switching performance across various ages ranging from children and adolescents (for a review, see Karbach and Unger 2014; Rueda et al. this volume) to younger and older adults (for a meta-analysis, see Karbach and Verhaeghen 2014; Guye et al. this volume) and also in clinical groups such as children with ADHD (e.g., Kray et al. 2012). For instance, Karbach and Kray (2009) showed that costs of switching between tasks were substantially reduced after four sessions of practice. Training net gains varied across training conditions from 0.85 SD to 1.88 SD, and a variable training (on a new set of stimuli and task rules in each training session) showed the smallest training gains. In a recent meta-analysis, Karbach and Verhaeghen (2014) reported training improvements in task switching in old age, with raw gains of about 0.90 SD and net gains (after subtracting the effects of active controls) of about 0.50 SD. Although nearly all studies report a reduction of latency switch costs, it should be noted that the findings on the reduction of error switch costs were rather mixed, probably because these costs are usually already relatively low at the beginning of the training.

Similar to the practice effects of training in task switching, most of the studies also reported near transfer, that is, training gains in an untrained switching task for various age ranges (e.g., Minear and Shah 2008). In line with the theoretical view that a considerable supply–demand mismatch is a precondition for inducing plasticity in task-switching performance, the amount of near transfer varies with age. For instance, in a task-switching training study of Karbach and Kray (2009), near-transfer gains on task-switching costs were much larger in healthy children and older adults than in younger adults. Given that the training was not adaptive, it may have induced a larger mismatch in children and older adults who also show age-related alterations in brain regions associated with task switching. Moreover, in the meta-analysis of Karbach and Verhaeghen (2014), clear near-transfer gains of EF training were shown for older adults. However, there is also evidence that for younger adults and adolescents, near-transfer gains are sometimes restricted to the general level of task switching (mixing costs) or to an uncued switching training (Pereg et al. 2013; Zinke et al. 2012), which again may induce a larger mismatch between task demands and brain supply. In line with this view are also results of Kray and Fehér (2014). In their study, demands on switching (single-task vs. mixed-task blocks), interference control (unambiguous or ambiguous stimuli), and working-memory demands (with or without task cues) varied between different training conditions. Interestingly, for younger adults transfer gains did not vary across these conditions. In contrast, older participants that were trained in resolving task interference (ambiguous groups) showed larger transfer gains than the participants that were trained on unambiguous stimuli inducing low task interference.

Results on far-transfer effects of training in task switching are rather mixed. While some studies found a relatively broad transfer to other EFs and even to measures of fluid intelligence (e.g., Karbach and Kray 2009), others found no far-transfer effects at all (Kray and Fehér 2014; Pereg et al. 2013). In one of our first task-switching training studies (Karbach and Kray 2009), we found far transfer to measures of inhibition and working memory and even to fluid intelligence for children and younger and older adults. Children with ADHD also showed far transfer to measures of inhibition and verbal working memory (Kray et al. 2012). In contrast, adolescents and young adults did not show broad far transfer to other task domains (Pereg et al. 2013; Zinke et al. 2012) of some studies. Recent meta-analytic evidence suggests that far transfer to other EFs and fluid intelligence is small but significant in older adults (Karbach and Verhaeghen 2014), but not present in younger adults (Jain et al. submitted for publication), again supporting the pattern of compensation effects reported in previous studies (see below).

Inhibition

Training studies investigating inhibition training are relatively scarce, and only very few of them examined the effects of inhibition training in childhood (cf. Kray and Ferdinand 2013). Results of these studies showed improved inhibitory control after training in early childhood. Given that intensive and adaptive working-memory training resulted in enhanced performance on measures of inhibitory control and reasoning in children with and without cognitive control impairments (for reviews, see Karbach and Unger 2014; Könen et al. this volume; Rueda et al. this volume), Thorell et al. (2009) tested whether inhibition and interference control training produced similar transfer gains. Preschoolers practiced three different tasks: the go/no-go, stop signal, and flanker task. The results indicated that this training, in contrast to working-memory training, did not lead to improvements on other cognitive tasks. One possible explanation for the lack of transfer might be that the variability of training was much larger in the inhibition and interference control training group than in the working-memory training group and previous work indicated that variability of training may hinder transfer in childhood (Karbach and Kray 2009). In contrast, a study from Rueda et al. (2005) applied a training battery including interference resolution and inhibition tasks to 4- and 6-year-old children. They reported transfer of training to reasoning tasks, a finding supporting the view that high demands on interference resolution during training may increase transfer (cf. Anguera et al. 2013).

Training studies including younger and older adults often relied on training on the Stroop task and showed better inhibitory control after practice. However, results regarding transfer of inhibitory control training to untrained tasks and abilities are ambiguous: Some studies reported transfer to new, untrained inhibition tasks and working-memory tasks, while others found no transfer (for a review, see Strobach et al. 2014).

Individual Differences

The studies reviewed so far showed that cognitive training can have positive effects on cognitive functions on the group level. However, individual differences in training-induced gains are often very large. This is particularly critical in children and older adults, because they are likely to differ more from each other than young adults, and between-group comparisons do little justice to individuals' strengths and weaknesses. Therefore, the question who benefits most from cognitive interventions has been more and more acknowledged (see Katz et al. this volume; Schmiedek this volume). Its importance is obvious from an applied point of view, especially when it comes to the adaptation of training interventions to populations with specific needs, such as children with neurocognitive disorders or older adults with specific cognitive impairments. Moreover, it also is of interest on the theoretical level, because individual differences in training-related benefits may help us understand the underpinnings of cognitive and neural plasticity. Also, the mismatch between environmental demands and brain supply that is induced may strongly vary between age groups and therefore needs to be considered for creating optimal training interventions.

Two prominent accounts have been put forward to describe and explain individual differences in training-related performance gains: First, the magnification account (also Matthew effect or scissor effect) assumes that individuals that are already performing very well will also benefit most from cognitive interventions. It is assumed that high-performing and well-educated participants have more efficient cognitive resources to acquire and implement new strategies and abilities. Thus, baseline cognitive performance at pretest should be positively correlated with the training-related gains, and the training should result in a magnification of age differences and individual differences. In fact, there are a number of earlier studies supporting this account, most of them from the field of memory-strategy training (see Rebok et al. 2007, for a meta-analysis).

Second, the compensation account assumes that high-performing individuals will benefit less from cognitive interventions, because they are already functioning at the optimal level and have less room for improvement. Thus, baseline cognitive performance should be negatively correlated with training gains, and age differences and individual differences should be reduced after the intervention (see Fig. 1). Evidence supporting this account comes from numerous studies focusing on EF training, revealing that training-related benefits were larger in children and older adults than in younger adults (e.g., Kray and Lindenberger 2000; for a review, see

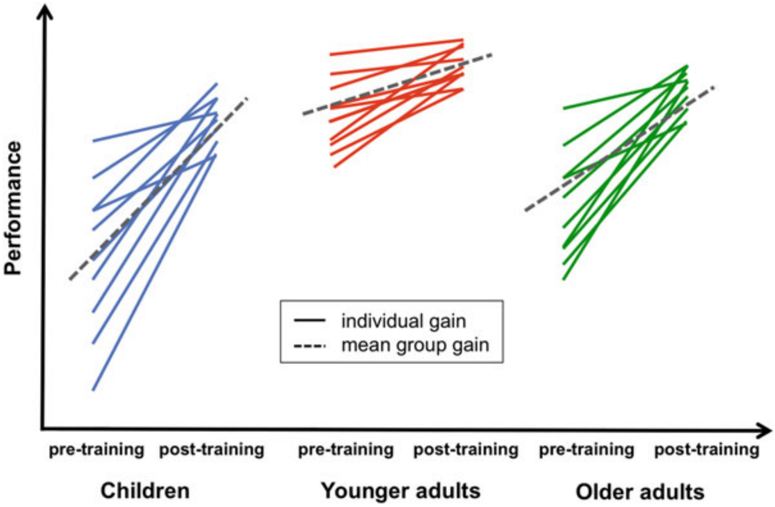

Fig. 1 Illustration of compensation effects after EF training: (1) reduction of interindividual differences in performance after the training, (2) reduction of age group differences after the training, and (3) negative correlation between baseline cognitive performance at pretest and training gains

Karbach and Unger 2014). While these studies were based on comparisons at the group level, recent studies also have analyzed correlations between baseline cognitive ability and training-related benefits, indicating that working-memory training yielded larger training and transfer effects in older adults with low cognitive performance at pretest (e.g., Zinke et al. 2013). Moreover, recent work has applied latent variable approaches to analyze individual differences in performance changes as well as correlations between baseline cognitive ability and training-related benefits. These studies also provided evidence for the magnification effects after memory-strategy training and compensation effects after task-switching training (cf. Könen and Karbach 2015).

Conclusions and Outlook

In sum, research focusing on EF training consistently showed that intensive training resulted in robust performance improvements on the training tasks, indicating that cognitive plasticity is considerable up to old age (see Guye et al. this volume). Most studies also reported near transfer of training to tasks measuring the same construct as the training task, and some studies even reported far transfer to different cognitive abilities in older age. However, especially when it comes to far transfer, the existing evidence is mixed and has recently inspired heated debates in the field. Yet, many inconsistent findings can be explained by large differences in the type and intensity of the training as well as in the research design and the analytical methods that have been applied (see Schmiedek this volume; Taatgen this volume). For instance, transfer seems to occur more consistently if (1) the training is process based and engages higher-order control processes, such as EF, instead of task-specific strategies, (2) the training and transfer tasks engage overlapping cognitive and neural resources, (3) the training is adaptive or variable (e.g., by including changing tasks and processes), and (4) the training puts a high load on the ability to resolve task interference (e.g., with high stimulus ambiguity or changing task modalities) (Anguera et al. 2013; Au et al. 2014; Karbach and Kray 2009; Karbach and Unger 2014; Kray and Fehér 2014; Kray and Ferdinand 2013; Strobach et al. 2014; Karbach and Verhaeghen 2014).

Current meta-analytic evidence suggests that there is small but significant far transfer of EF training across the adult lifespan, including transfer to other components of EF, attention, and fluid intelligence (e.g., Au et al. 2014; Karbach and Verhaeghen 2014; but see Melby-Lervåg and Hulme 2015). Thus, given that the effect sizes for far transfer seem to be relatively small, the question really is whether these effects should be considered relevant. In accordance with Oberauer (2015), we think that these effects indeed are extremely relevant. From a scientific point of view, they are very informative for our theoretical conception of EF. The fact that EF training transfers to other components of EF but that these transfer effects are smaller than the gains on the training tasks is more in line with the idea that EF is a set of separable but highly correlated control functions. From a more applied point of view, even small improvements in cognitive performance can be extremely relevant for individuals with cognitive deficits (see Alloway et al. this volume; Belleville et al. this volume). Moreover, these small effects could be much increased if we understood exactly which features of training moderate the effectiveness of the intervention and how this effectiveness can be maximized (cf. Oberauer 2015). Future studies will have to focus on these issues, for instance, by considering individual differences in motivational (e.g., training motivation, self efficacy; see Katz et al. this volume) and social aspects (e.g., educational background or socioeconomic status) as well as genetic predispositions of the participants. Current evidence suggests those and other variables may significantly moderate the amount of training-induced gains and the scope of transfer, but clearly more research is needed to understand how they contribute to the effectiveness of EF training (see Colzato and Hommel this volume).

References

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., et al. (2013). Video game training enhances cognitive control in older adults. *Nature, 501*, 97–101.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2014). Improving fluid intelligence with training on working memory: A meta-analysis. *Psychonomic Bulletin & Review, 22*, 366–377.

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology, 49*, 5–28.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624–652.

De Jong, R. (1995). The role of preparation in overlapping-task performance. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 48A*, 2–25.

Jain, S., Verhaeghen, P., & Karbach, J. (submitted for publication). Working memory training trains working memory, but little else: A comprehensive meta-analysis on working memory training effects in younger adults.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task- switching training. *Developmental Science, 12*, 978–990.

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*, 2027–2037.

Könen, T., & Karbach, J. (2015). The benefits of looking at intraindividual dynamics in cognitive training data. *Frontiers in Psychology, 6*, 615.

Kray, J., & Fehér, B. (2014, July). *Age differences in the transfer of task-switching training: The impact of working memory and inhibition demands*. Paper presented at the 12th International Conference on Cognitive Neuroscience (ICON), Brisbane, Australia.

Kray, J., & Ferdinand, N. K. (2013). How to improve cognitive control in development during childhood: Potentials and limits of cognitive interventions. *Child Development Perspectives, 7*, 121–125.

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can task-switching training enhance executive control functioning in children with attention deficit/-hyperactivity disorder? *Frontiers in Human Neuroscience, 5*, 180.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15*, 126–147.

Liepelt, R., Strobach, T., Frensch, P., & Schubert, T. (2011). Improved intertask coordination after extensive dual-task practice. *The Quarterly Journal of Experimental Psychology, 64*, 1251–1272.

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136*, 659–676.

Maquestiaux, F., Hartley, A. A., & Bertsch, J. (2004). Can practice overcome age-related differences in the psychological refractory period effect? *Psychology and Aging, 19*, 649–667.

Melby-Lervåg, M., & Hulme, C. (2015). There is no convincing evidence that working memory training is effective: A reply to Au et al. (2014) and Karbach and Verhaeghen (2014). *Psychonomic Bulletin and Review, 22*, 366–377.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167–202.

Minear, M., & Shah, P. (2008). Training and transfer effects in task switching. *Memory & Cognition, 36*, 1470–1483.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wagner, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective, & Behavioral Neuroscience, 12*, 241–268.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson (Ed.), *Consciousness and self-regulation* (pp. 1–18). New York: Plenum Press.

Oberauer, K. (2015). *Training of intelligence: A question of intelligent training*. Retrieved from http://www.psychonomic.org/featured-content-detail/training-of-intelligence-question-of-intelligent-t

Pereg, M., Shahar, N., & Meiran, N. (2013). Task switching training effects are mediated by working-memory management. *Intelligence, 41*, 467–478.

Rebok, G. W., Carlson, M. C., & Langbaum, J. B. (2007). Training and maintaining memory abilities in healthy older adults: Traditional and novel approaches. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 62*, 53–61.

Rueda, M. R., Rothbart, M. K., McCandliss, M. D., Saccomanno, L., & Posner, M. L. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Science, 102*, 14931–14936.

Ruthruff, E., Van Selst, M., Johnston, J. C., & Remington, R. W. (2006). How does practice reduce dual-task interference: Integration, automatization, or simply stage-shortening? *Psychological Research, 70*, 125–142.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin, 138*, 628–654.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283*, 1657–1661.

Strobach, T., Salminen, T., Karbach, J., & Schubert, T. (2014). Practice-related optimization and transfer of executive functions: A general review and a specific realization of their mechanisms in dual tasks. *Psychological Research, 78*, 836–851.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*, 106–113.

Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience, 6*, 41.

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2013). Working memory training and transfer in older adults: Effects of age, baseline performance, and training gains. *Developmental Psychology, 50*, 304–331.

Part IV
Multidomain Trainings

Action Video-Game Training and Its Effects on Perception and Attentional Control

C. Shawn Green, Thomas Gorman, and Daphne Bavelier

Introduction

Over the past 40 years, video game play has grown from a niche activity into a pervasive and abundant part of modern life. Over half of the United States population now plays video games, with over 130 million of these individuals being considered "regular" video game players (i.e., playing more than 3 h of video games per week—ESA 2015). And although video games were originally, and for the most part continue to be, an *entertainment* medium, there has nonetheless been significant scientific interest in the possibility that video gaming may have significant effects on the human brain and human behavior. While much of this research has focused on potential negative outcomes (e.g., effects related to aggression or addiction—Anderson et al. 2010), there exists a growing body of research outlining positive effects of video game play as well. This chapter will specifically focus on the positive impact that playing one particular type of video game, known as "action video games," has on perceptual and attentional skills.

The "Curse of Specificity"

Before discussing the various effects associated with action video game play, it is worth considering why it is interesting in the first place that something like video game play could alter core perceptual or attentional abilities. Indeed, one's first

---

C.S. Green (✉) • T. Gorman
Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA
e-mail: cshawn.green@wisc.edu; tegorman@wisc.edu

D. Bavelier
Department of Psychology, University of Geneva, Geneva, Switzerland
e-mail: Daphne.Bavelier@unige.ch

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_10

intuition might be that, “Many video games place extreme demands on the perceptual and attentional systems—wouldn’t it make sense that playing these games would lead to such benefits?”. Interestingly though, such an intuition runs counter to the effects seen in many classic perceptual training experiments, wherein individuals were trained by repeatedly practicing a single perceptual task. It is certainly the case that, when given appropriate training, humans will tend to improve their performance on most tasks. However, it is typically the case that these improvements fail to generalize to new contexts or situations. For instance, in one classic experiment, participants were trained to identify two complex visual gratings. Although participants quickly learned this task, when seemingly minor changes were made to the experimental setup (e.g., doubling or halving the spatial frequency), participants returned to chance levels of performance and had to learn the task under the new set of conditions from scratch (Fiorentini and Berardi 1980). This type of failure to generalize learning has been an extremely common finding in the perceptual and cognitive domains (Sagi 2011). There has thus been extreme interest in recent findings that several types of experience—including the focus of this review, action video game training—appear to overcome the tendency toward task-specific learning and instead promote more general enhancements in behavioral performance.

“Action” Video Games

One common theme that has linked essentially all of the research that has been conducted on the effects of video games over the past several decades is that the content of the games is key. Playing “video games” does not increase empathy and pro-social behaviors; playing video games that contain specific types of pro-social content increases empathy and pro-social behaviors. Similarly, playing “video games” does not increase aggressive thoughts; playing video games that contain specific types of antisocial content increases aggressive thoughts (Anderson et al. 2010). In the study of perceptual and attentional skills, the content that has been of most interest is what has been dubbed “action” content.

Action video games have a number of properties that together distinguish this genre from other types of video games. These include extreme temporal processing demands (e.g., items that move exceptionally quickly or that pop in and out of view); the requirement to strongly attend to task-relevant items near the center of the screen while also monitoring a large field of view (as important targets usually first present themselves at the edges of the screen); substantial amounts of visual clutter (thus putting the ability to select task-relevant information and reject task-irrelevant information at a premium); complex motor response demands, and considerable perceptual and cognitive load (e.g. many independently moving items to track; many distinct plans to evaluate and select amongst; for a more thorough discussion, see Spence and Feng 2010). First-person shooters (e.g., Call of Duty) and third-person shooters (e.g., Gears of War) are common subgenres that involve this set of characteristics, but the action genre as it is commonly defined in the field also includes certain car-driving games as well as various newer hybrid genres such as 'action-role-playing games' (e.g., Skyrim) and 'action-adventure games' (e.g., Grand Theft Auto). The empirical findings that we will discuss below are specifically related to these types of games and not other types of games.

Studying the Effects of Action Video Games

In discussing the impact of action gaming, it is critical to note how studies are conducted in this domain and how the design of the study impacts the types of inferences that can be made (see also Green et al. 2014). In particular, the mass popularity of video games allows for cross-sectional approaches to be utilized in addition to pure experimental methods. Indeed, cross-sectional approaches—wherein the behavioral performance of individuals who play substantial amounts of action video games (often labeled "action video game players" or "AVGPs") is contrasted against the behavioral performance of individuals who do little gaming ("non-video game players" or "NVGPs")—are undoubtedly the most common study design in the field. Such studies have the advantage that participants with clearly defined and different types of experience can be recruited, and thus potential differences in behavior can be quickly evaluated. The clear disadvantage though is that such studies, like all correlational approaches, cannot be used to draw causal inferences. After all, if one observes that AVGPs greatly outperform NVGPs on a test of visual acuity, there is no way to determine if this reflects an effect of game experience or if instead individuals born with better acuity tend to gravitate toward action video games. Thus, in order to demonstrate a causal relationship, long-term intervention studies must be performed wherein a group of NVGPs is first selected and pretested on the behavioral measure(s) of interest. The participants are then randomly assigned to play either an action video game or a control video game (that is chosen to match the action game in dimensions such as identification with character, sense of learning/achievement, etc.) for anywhere from 10 to 50 h depending on the study. Critically, this training must be distributed over the course of many days/weeks as video game training, like essentially all learning, is far less efficient when it is highly massed over time (e.g., 5 four-hour long sessions) as compared to when it is distributed over time (e.g., 20 one-hour long sessions) (Stafford and Dewar 2014). Finally, at least 24 h after the last gaming session, participants are tested again on the measure(s) of interest. A causal relationship between action video game training and enhanced abilities is indicated by a significantly greater gain from pre- to post-test in the action-trained group than the control-trained group.

Effects of Action Video Games on Perceptual Skills

Vision: Action video game playing has been repeatedly linked to augmented performance in perceptual tasks. For example, one of the most fundamental aspects of vision is contrast sensitivity—the ability to detect differences in luminance in adjacent parts of the visual world (as changes in luminance frequently demarcate important parts of the scene, such as object boundaries). In cross-sectional work, AVGPs have been seen to have enhanced contrast sensitivity as compared to NVGPs (i.e., AVGPs could detect finer differences in luminance than NVGPs; Li et al. 2009). The same study also established a causal relationship between action video game play and enhanced contrast sensitivity via a 50-h intervention study wherein NVGPs trained on an action video game showed significantly greater improvements in contrast sensitivity than NVGPs trained on a nonaction video game.

In cross-sectional work, researchers have also observed enhancements in a number of basic aspects of peripheral vision. For instance, AVGPs have been shown to perform better than NVGPs in the Goldmann visual perimetry test (Buckley et al. 2010). Here individuals sit in front of a large white bowl that encompasses the majority of their visual field. Small lights are turned on at random locations throughout the field, and the individual must indicate whenever a light is observed. AVGPs have also been shown to have enhancements in peripheral acuity (i.e., visual resolution—an eye chart measures the same ability in the central visual field) as compared to NVGPs (Green and Bavelier 2007) as well as enhancements in certain types of motion processing (Hutchinson and Stocks 2013).

Speed of Processing: A number of papers have demonstrated that AVGPs show increases in speed of processing. For example, Dye and colleagues (2009) utilized what is known as the "Brinley plot" technique to examine this issue. Here, AVGP reaction times on a wide variety of tasks (from experiments run by several independent labs) were plotted against NVGP reaction times on the same tasks. AVGPs were found to respond approximately 12 % faster than NVGPs across all of the tasks considered, without any change in accuracy (i.e., the effect could not be attributed to a simple speed-accuracy tradeoff). A similar finding was seen when examining just those studies from the literature employing intervention studies (i.e., testing the causal link).

More recently, several groups have examined this question experimentally via the framework of the theory of visual attention (TVA). This framework allows researchers to segregate performance into a number of distinct aspects (e.g., related to basic perceptual thresholds, speed of processing, short-term memory storage capacity, top-down attentional control). Specifically, using this framework, Wilms and colleagues (2013) found that AVGPs showed a specific enhancement in the speed with which visual information is transmitted to short-term memory. Schubert and colleagues (2015) also observed greater speed of processing in AVGPs as compared to NVGPs (restricted to the lower visual field in their case) as well as heighted perceptual thresholds in AVGPs. However, no changes in these aspects were noted in NVGP participants trained on an action video game (as compared to NVGPs trained on a control video game), leaving the causal link still in question.

Perceptual Decision-Making: There is also evidence that action video game playing increases the efficiency of making perceptual decisions—in other words, the ability to accumulate perceptual information over time in the service of a particular decision, for example, as when having to decide in which direction a school of fish may be swimming. This phenomenon has been observed both in a cross-sectional work contrasting AVGPs and NVGPs and in a long-term (50 h) intervention study

(Green et al. 2010; although see Van Ravenzwaaij et al. 2014). Along similar lines, recent work suggests that the superior performance seen by action gamers in perceptual tasks is driven by an enhanced ability to generate perceptual templates of the task at hand (Bejjanki et al. 2014).

Multisensory Integration: While most of the research examining changes in perceptual processing as a function of action video game play has focused on the visual domain, some effects have also been observed in experiments requiring multisensory processing. For example, Donohue et al. (2010) found that when individuals were presented with visual and auditory information sequentially (e.g., either the visual stimulus first and then the auditory stimulus or the auditory stimulus first and then the visual stimulus), AVGPs were better able to distinguish the correct temporal order. This finding indicates a relationship may exist between action video game play and multisensory processing, although intervention studies are still needed.

Effects of Action Video Games on Attentional Control

Many of the largest and most consistently observed benefits of action video game play have been in attentional control tasks. These are tasks that require selecting and enhancing the processing gain of task-relevant items while ignoring/reducing the processing gain of task-irrelevant information. Here we divide the effects into spatial attention (i.e., as is needed when task-relevant and task-irrelevant information is presented simultaneously on different parts of the screen), temporal attention (i.e., as is needed when task-relevant and task-irrelevant information is presented on the screen at different times), and attentional capacity (i.e., the maximum number of items that can be attended); for effects of action video games on higher-level executive functioning, see Strobach and Schubert this volume.

Spatial Selective Attention: Action video games have been linked with many enhancements in spatial visual attention. For instance, one task commonly believed to assess the spatial resolution of visual attention is the crowding task. Here a peripheral target must be identified when spatially surrounded by distracting items. Green and Bavelier (2007) found that AVGPs showed enhanced performance in such a crowding task as compared to NVGPs (i.e., AVGPs could identify targets even when the distracting items were placed very close to the targets). The causal effect of the action gaming was confirmed via a 30-h intervention study.

Other common measures of spatial selective attention include various visual search tasks. For instance, in the Useful Field of View task, participants must locate a peripheral target (presented either 10°, 20°, or 30° from fixation) from amongst a field of distracting objects. Enhanced performance on this task has been consistently observed in AVGPs as compared to NVGPs, and several different groups have demonstrated a causal link via intervention studies (Dye and Bavelier 2010; Feng et al. 2007; Green and Bavelier 2003). Similar results have been observed in other spatial selective attention designs (West et al. 2008). Advantages have also been noted in standard visual search tasks. Specifically, AVGPs are less effected by increasing numbers of distractors when searching for hard-to-find targets than NVGPs (Hubert-Wallander et al. 2011).

Temporal Selective Attention: In addition to space, action gaming appears to also enhance the ability to attend to stimuli selectively across time. This ability is commonly measured with the attentional blink task. In one version of the attentional blink task, participants view a series of rapidly presented black letters. At some point in the stream, one white letter is presented. At the end of the stream, the participant will be asked to indicate the identity of this letter. Additionally, 50 % of the time, a black "X" is presented at a point after the white letter. The participant is thus also asked to indicate whether or not an "X" appeared after identifying the white letter. When these two targets are presented within around 400 ms of each other, participants have difficulty detecting the second of the two targets (i.e., the "X"). Thus, the presence of the initial target is said to have caused attention to blink. As time between the targets increases, accuracy in attending to the second target also increases. Playing action video games has been repeatedly associated with a reduction in the duration of this blink, both in cross-sectional and in intervention studies (Dye and Bavelier 2010; Green and Bavelier 2003). Similar results have been observed in various other measures requiring precision in temporal attention, such as in temporal masking tasks (Li et al. 2010; Pohl et al. 2014)—wherein the presence of distracting items presented either just before or just after a stimulus (at nearby, but not spatially overlapping locations) adversely affects target identification. Specifically, AVGPs showed a reduction in the extent to which such masking effects were observed as compared to NVGPs.

Attentional Capacity: Finally, the capacity of visual attention has been shown to increase as a result of action video gaming. One measure of attentional capacity, the multiple-object tracking (MOT) paradigm, requires individuals to track several moving distinctive targets (e.g., red dots) amongst a field of moving distractors (e.g., green dots). After a few seconds, the red dots change to become the green dots, meaning that the targets must be tracked despite being visually indistinguishable from the distractors. Enhancements in multiple-object tracking tasks have been seen in AVGPs as compared to NVGPs (Dye and Bavelier 2010), and a causal relationship has been established via an intervention study (Green and Bavelier 2006). The same study found an AVGP advantage in an enumeration task, which measures the ability to quickly and accurately report the number of briefly flashed items in a display.

Possible Neural Bases of Action Video Game Effects

While the vast majority of work in this domain has been behavioral in nature, a few recent publications have started to examine the underlying neural changes that may subserve the observed behavioral changes. For example, Mishra et al. (2011) examined EEG activity related to processing of task-relevant and task-irrelevant information as a function of action game experience. Interestingly, while both AVGPs and

NVGPs showed enhancements in processing the information relevant to the task (i.e., as would be consistent with increases in gain), the AVGPs' brain activity showed greater suppression of activity related to task-irrelevant information as compared to the NVGPs. Furthermore, the degree of suppression was well-correlated with differences in behavioral performance on the psychological task (where AVGPs again outperformed NVGPs), lending further support to the belief that improved ability to flexibly modulate neural gain is a key component of the neural basis of action video game-related improvements in attentional abilities. Several additional ERP and fMRI studies have also found a relationship between action gaming and changes in neural activity related to visuospatial selective attention (Bavelier et al. 2012a; Krishnan et al. 2013), including one intervention study (Wu et al. 2012).

Emerging Framework: Action Video Games and "Learning to Learn"

Work on action video game training, and indeed, cognitive training in general, has to date largely focused on the "immediate transfer" form of learning generalization. This is when training on some "Task A" results in immediate enhancements relative to expectations when first performing some new "Task B." We have recently suggested though that the broad benefits seen as a result of action video game play may not in fact reflect "immediate transfer" but may instead reflect what is known as "learning to learn" (Bavelier et al. 2012b). In learning to learn, training on some "Task A" may not produce any immediate benefits when first performing some new "Task B," but instead the training on "Task A" allows "Task B" to be learned more quickly than otherwise would have been the case.

As an illustrative example, consider a case where training on some "Task A" improves top-down attentional abilities in a truly general fashion. If, after this training, participants are then asked to perform a novel-shape categorization task (i.e., on each trial the participants are shown a novel shape that is drawn from one of two possible categories and they are asked to indicate the shape's category membership), no immediate transfer would be expected. Indeed, although their heightened top-down attentional abilities would allow the participants to extract more information from each novel shape that is presented, it does not provide them with information about the actual statistical structure indicative of category membership. This statistical structure must be learned via experience. The heightened attention though will allow the statistical structure to be learned more quickly by making better data available to the learning system.

Consistent with this theoretical framework, we have recently shown that AVGP and NVGP performance on a new visual discrimination task is initially very similar (i.e., within the first few trials—Bejjanki et al. (2014)). However, the AVGPs' performance on the task improved much more rapidly than the NVGP performance. Similar findings have also been obtained in a visuomotor task (Gozli et al. 2014).

Interestingly, many of the mechanisms believed to underlie action video game-based enhancements (e.g., heightened attentional control) are the same as those posited to occur via other forms of cognitive training. However, because generalization in these domains has only ever been evaluated in the traditional pretest/posttest manner (i.e., where performance is averaged over a single block of pretest trials and then compared to performance averaged over a single block of posttest trials), the extent to which "transfer" versus "learning to learn" is observed in these domains is as of yet unclear. Adjudicating between these possibilities would require a design wherein individuals undergo a full bout of learning on the generalization measures after training so as to be able to measure the time course with which the generalization measures are learned.

Potential Applications of Action Video Game Training

The broad benefits to perceptual and attentional control abilities induced by action video game play have led to a great deal of interest in potential practical applications of dedicated action video game training. For instance, research has shown that action video games may have the potential to improve the vision of individuals with amblyopia (colloquially known as "lazy eye"). This is of sizeable importance as previous research has suggested that it is difficult to improve amblyopic vision in adulthood via dedicated training. However, Li et al. (2011) demonstrated that training with either action video games or nonaction video games resulted in significant improvements in both acuity and, in many cases, stereovision (i.e., 3D) in adult amblyopes. Beyond rehabilitative purposes, several studies have also suggested that action video game training may result in useful benefits for individuals whose jobs involve demanding visual, visuomotor, or attentional demands. This includes both pilots and laparoscopic surgeons (McKinley et al. 2011; Schlickum et al. 2009).

Future Directions

One of the most important future directions in this domain is to begin to better understand the elements within action video games that are most responsible for the benefits to vision and visual attention at a mechanistic level. We know that essentially all commercially successful video games, including those in the action genre, share a set of characteristics that make them effective learning tools. These characteristics include mechanics such as providing intrinsic and extrinsic reinforcement, proper modulation of task difficulty, the use of active learning with immediate and informative feedback, engendering a beneficial level of physiological arousal, and providing substantial variety in experience. Because these characteristics are found in all commercially successful games though, they cannot be the key features that promote improved perception and visual attention (i.e., perhaps necessary, but not sufficient). By understanding the effects of games that fall outside of the classic "action genre" (i.e., real-time strategy games) that share some, but not all, components of action video games, we may be able to elucidate the critical game components needed to produce the desired improvements.

Conclusions

To summarize, there is now compelling evidence indicating that action video game play engenders clear enhancements in an array of perceptual, attentional, and cognitive skills. This evidence includes both a large number of cross-sectional studies and a number of well-controlled intervention studies that have indicated that the relationship between action game play and augmented performance is indeed causal. These findings hold the promise of numerous real-world applications, from rehabilitation of visual deficits to job-related training, but whether the results scale from lab measures to real-life remains to be firmly established.

References

Anderson, C. A., Shibuya, A., Ihori, N., Swing, E. L., Bushman, B. J., Sakamoto, A., et al. (2010). Violent video game effects on aggression, empathy, and prosocial behavior in eastern and western countries: A meta-analytic review. *Psychological Bulletin, 136*(2), 151.

Bavelier, D., Achtman, R. L., Mani, M., & Föcker, J. (2012a). Neural bases of selective attention in action video game players. *Vision Research, 61*, 132–143.

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012b). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35*, 391–416.

Bejjanki, V. R., Zhang, R., Li, R., Pouget, A., Green, C. S., Lu, Z. L., et al. (2014). Action video game play facilitates the development of better perceptual templates. *Proceedings of the National Academy of Sciences, 111*(47), 16961–16966.

Buckley, D., Codina, C., Bhardwaj, P., & Pascalis, O. (2010). Action video game players and deaf observers have larger Goldmann visual fields. *Vision Research, 50*(5), 548–556.

Donohue, S. E., Woldorff, M. G., & Mitroff, S. R. (2010). Video game players show more precise multisensory temporal processing abilities. *Attention, Perception, & Psychophysics, 72*(4), 1120–1129.

Dye, M. W., Green, C. S., & Bavelier, D. (2009). Increasing speed of processing with action video games. *Current Directions in Psychological Science, 18*(6), 321–326.

Dye, M. W., & Bavelier, D. (2010). Differential development of visual attention skills in school-age children. *Vision Research, 50*(4), 452–459.

Entertainment Software Association. (2015). E*ssential facts about the computer and video game industry*. Retrieved July 22, 2015, from http://www.theesa.com/wp-content/uploads/2015/04/ESA-Essential-Facts-2015.pdf/

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*(10), 850–855.

Fiorentini, A., & Berardi, N. (1980). Perceptual learning specific for orientation and spatial frequency. *Nature, 287*, 43–44.

Gozli, D. G., Bavelier, D., & Pratt, J. (2014). The effect of action video game playing on sensorimotor learning: Evidence from a movement tracking task. *Human Movement Science, 38*, 152–162.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534–537.

Green, C. S., & Bavelier, D. (2006). Enumeration versus multiple object tracking: The case of action video game players. *Cognition, 101*(1), 217–245.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*(1), 88–94.

Green, C. S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology, 20*(17), 1573–1579.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*(6), 756–772.

Hubert-Wallander, B., Green, C. S., Sugarman, M., & Bavelier, D. (2011). Changes in search rate but not in the dynamics of exogenous attention in action videogame players. *Attention, Perception, & Psychophysics, 73*(8), 2399–2412.

Hutchinson, C. V., & Stocks, R. (2013). Selectively enhanced motion perception in core video gamers. *Perception, 42*(6), 675–677.

Krishnan, L., Kang, A., Sperling, G., & Srinivasan, R. (2013). Neural strategies for selective attention distinguish fast-action video game players. *Brain Topography, 26*(1), 83–97.

Li, R. W., Ngo, C., Nguyen, J., & Levi, D. M. (2011). Video-game play induces plasticity in the visual system of adults with amblyopia. *PLoS Biol, 9*(8), 1793.

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience, 12*(5), 549–551.

Li, R., Polat, U., Scalzo, F., & Bavelier, D. (2010). Reducing backward masking through action game training. *Journal of Vision, 10*(14), 33.

McKinley, R. A., McIntire, L. K., & Funke, M. A. (2011). Operator selection for unmanned aerial systems: Comparing video game players and pilots. *Aviation, Space, and Environmental Medicine, 82*(6), 635–642.

Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of action videogame players in an attention-demanding task. *The Journal of Neuroscience, 31*(3), 992–998.

Pohl, C., Kunde, W., Ganz, T., Conzelmann, A., Pauli, P., & Kiesel, A. (2014). Gaming to see: Action video gaming is associated with enhanced processing of masked stimuli. *Frontiers in Psychology, 5*, 70.

Sagi, D. (2011). Perceptual learning in Vision Research. *Vision Research, 51*(13), 1552–1566.

Schlickum, M. K., Hedman, L., Enochsson, L., Kjellin, A., & Felländer-Tsai, L. (2009). Systematic video game training in surgical novices improves performance in virtual reality endoscopic surgical simulators: A prospective randomized study. *World Journal of Surgery, 33*(11), 2360–2367.

Schubert, T., Finke, K., Redel, P., Kluckow, S., Müller, H., & Strobach, T. (2015). Video game experience and its influence on visual attention parameters: An investigation using the framework of the Theory of Visual Attention (TVA). *Acta Psychologica, 157*, 200–214.

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*(2), 92.

Stafford, T., & Dewar, M. (2014). Tracing the trajectory of skill learning with a very large sample of online game players. *Psychological Science, 25*(2), 511–518.

Van Ravenzwaaij, D., Boekel, W., Forstmann, B. U., Ratcliff, R., & Wagenmakers, E. J. (2014). Action video games do not improve the speed of processing in simple perceptual tasks. *Journal of Experimental Psychology: General, 143*(5), 1794–1805.

West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision, 8*(16), 13.

Wilms, I. L., Petersen, A., & Vangkilde, S. (2013). Intensive video gaming improves encoding speed to visual short-term memory in young male adults. *Acta Psychologica, 142*(1), 108–118.

Wu, S., Cheng, C. K., Feng, J., D'Angelo, L., Alain, C., & Spence, I. (2012). Playing a first-person shooter video game induces neuroplastic change. *Journal of Cognitive Neuroscience, 24*(6), 1286–1293.

Video Game Training and Effects on Executive Functions

Tilo Strobach and Torsten Schubert

Introduction

The video game industry expands as the number of its clients constantly increases. Surveys show that 58 % of the Americans play video games and 25 million Germans play games several times a month; this frequent use of video games is independent of gender, education, and income (e.g., BIU 2012). Cognitive research provided evidence in recent years that experienced video gamers outperform non-experienced people in a number of basic cognitive functions (e.g., Bavelier et al. 2012; see also Green and Bavelier this volume). These positive effects in video gamers led us to focus on the particular effects of video game experience on executive functions.

Executive functions typically control our behavior when we perform in demanding and complex situations including situations in which the management of different tasks or task sequences is required. These functions define a set of general-purpose control mechanisms, often linked to the prefrontal cortex of the brain, that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition (Baddeley 1986; Miyake et al. 2000). Different types of executive functions have been classified by different authors, e.g., shifting, dual tasking, updating, and inhibition. While their processing can be time-consuming and inefficient under unpracticed conditions, recent studies suggest that executive functions can be improved as a result of extensive training and training-induced gains can even be transferred to non-practiced situations (Strobach et al. 2014). This training-related plasticity is particularly relevant when aiming to compensate for the strong

---

T. Strobach (✉)
Department of Psychology, Medical School Hamburg,
Hamburg, Germany
e-mail: tilo.strobach@medicalschool-hamburg.de

T. Schubert
Department of Psychology, Martin Luther University Halle, Halle, Germany
e-mail: torsten.schubert@psych.uni-halle.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_11

age-related declines in executive functions and frontal lobe tasks (Raz 2000; Strobach et al. 2015).

The present chapter includes a concise review of studies investigating the potential optimization and transfer of different types of executive functions as a result of video game experience. Here, we primarily focus on studies within the action video game genre. So far, many studies have been concerned with assessing the impact of action games on executive function as action video game playing seems highly adequate for training executive control skills. In action video games, gamers have to control and conduct multiple simultaneous tasks at a high speed. Important information, such as interim targets and assignments, must be updated all the time (Spence and Feng 2010), and gamers need to adapt their actions and action goals under permanently changing task conditions (Bavelier et al. 2012). The most prominent action games are first-person shooters such as *Counter-Strike*, *Unreal Tournament*, or *Call of Duty* and third-person shooters like *Grand Theft Auto*. In these games, gamers play in an open virtual world with a first-person or third-person perspective on the main character. They usually have to fight against enemies, find objects, and navigate through this world.

In the video game literature, two perspectives were introduced to generally explain mechanisms of transfer effects from video gaming to situations beyond the game context (e.g., laboratory-based transfer to measures of executive functioning). The first explanation to account for potential transfer effects is that these effects are all due to a single more general level of improvement, which then aids performance in all transfer tasks. One proposal of general training-related transfer is that video gamers improve in probabilistic inference, or “learning to learn.” As a result of training, according to this “learning to learn” theory, action video gamers generally become more effective in using evidence from repeated presentations of a task to guide their decision-making and allocation of cognitive resources (Bavelier et al. 2012). This “learning to learn” theory predicts that, as a result of appropriate action video game training, there should be transfer effects to all types of executive functions, i.e., shifting, dual tasking, updating, and inhibition.

In contrast, transfer effects may be due to video games having several separate demands in common with laboratory tasks that measure perception, attention, or cognition (Oei and Patterson 2015). According to this “common demands” theory (Dahlin et al. 2008), transfer from action video games to executive function measures is specific and depends on similarities between the trained video game and the laboratory task. There may be some specific learned properties of the game, but there may also be higher level more abstract procedures that are developed during the game that may allow transfer from the game to behavioral measures. Taatgen (this volume) argues that skills required to perform a task can be broken down into “primitive information processing elements” of which some are task-specific and some are general. If two tasks share overlapping elements, those learned from training can be applied in test situations, producing transfer. As a consequence, alternatively to the prediction of the “learning to learn” theory, the “common demands” theory predicts that transfer effects are not general for all types of executive functions (i.e., shifting, dual tasking, updating, and inhibition), but are specific for the functions where the game and task share common demands. In a final section, we will evaluate the literature on action game experience and effects on executive functions regarding these theories (i.e., "learning to learn," "common demands"), explaining general mechanisms of transfer effects.

Shifting

Also referred to as "attention switching" or "task switching," this type of executive functions concerns the ability to shift back and forth between multiple tasks, operations, or mental sets (Monsell 2003). Shifting involves the disengagement from irrelevant information (e.g., the task set of a previous task) and/or the active engagement in relevant information (e.g., the task set of an upcoming task). Evidence for optimized shifting derives from studies on task switching practice (e.g., Berryhill and Hughes 2009; Karbach and Kray 2009; Strobach et al. 2012b): These studies showed that performance costs associated with the shifting processes (e.g., task-switch costs reflected by larger reaction times [RTs] in trials with switches between different tasks in contrast to trials with task repetitions) are reduced with practice and, consequently, illustrate optimization of executive functioning of shifting. Relevant for the present context, persons with experience in action video games showed less switch costs than non-gamers in a paradigm including predictable switches and repetitions (e.g., Colzato et al. 2010). This provides first—although cross sectional—evidence for optimized executive functions in terms of improved shifting abilities.

Do these advantages in gamers mean that there is a causal link between video game experience and optimized executive functions? The answer is no, not exactly (Green et al. 2014). Advantages in gamers do not have to be a result of video game experience (Schubert and Strobach 2012). The attributes could be, for instance, inherited or just given before they started playing video games (which would mean that the attributes would then be independent of the video game experience). As a consequence, research on video games has implemented more and more training experiments with non-gamers in order to assess potential causal links between game experience and optimized executive functions. As an example, Strobach et al.'s (2012a) training in young adults consisted of 15 one-hour sessions, in which two groups of non-gamers played different games. The first group worked on a puzzle game with only one main task and only low executive function demands. The second group played an action game with high executive function demands. In a test on task-switching performance before the training started, the switch costs do not differ between both groups of puzzle and action gamers. Afterwards, however, the results indicated lower switch costs in the action game group in comparison to the puzzle group. This training study shows that switch costs can be reduced with action game training specifically and that this reduction cannot be traced to inherited, given, or previously acquired attributes. These results provide evidence for a causal link between video game experience and optimized executive functions for shifting between different tasks. Further, this finding was generalized to numerous alternative task-switching situations, sharing varying numbers of input and output processors with typical action video games (Cain et al. 2012; Green et al. 2012).

However, the task switching advantage of non-gamers after action video game training might be limited to situations with predictable task switches and the requirement to constantly update working memory: how many trials have been completed in the current task and to count down for the upcoming switch (Green et al. 2012; Strobach et al. 2012a). In a task-switching paradigm with the random and unpredictable occurrence of switch and repetition trials (e.g., the particular task is cued), updating of working memory is not required, and participants do not need to take into account the nature of previous trials. There is no evidence for superior shifting between tasks in action video gamers vs. non-games as well as after training of an action game, strategy game, or puzzle game in such an unpredictable task-switching situation (Boot et al. 2008; Oei and Patterson 2014). The observation of advanced task-switching performance of action video gamers predominantly in situations with predictable task switches might point to an impact of superior updating functions related to this group of participants. In our view, this tempting assumption may represent an issue for fruitful future investigations (see also the updating section).

A further mechanism that may specifically explain action video gamers' improved performance in task-switching situations is a superior ability to control selective attention and thus active engagement in relevant information of an upcoming task (i.e., selective attention-dependent preparation, Karle et al. 2010). The effectiveness of engagement might be that relevant information of an upcoming task is only activated to a degree in working memory that is necessary to efficiently perform this task. In such a case, the following effort for an effective disengagement of this task information is reduced to a minimal degree. The reduced effort for task disengagement might free processing resources for alternative tasks, a potentially effective strategy for successful performance in complex gaming contexts.

Dual Tasking

But do the gamers also have advantages when they perform different tasks simultaneously at the same time (instead of a sequential performance of different tasks as in the task-switching paradigm)? Are there any signs of optimized executive functions when the gamers are put in dual-task situations? Dual-task situations require the coordination of different tasks and task information due to executive functions (among others, dual tasks require the control of which task is performed first and which task second, Schubert 2008; Szameitat et al. 2006). For instance, this coordination leads to longer RTs in dual-task situations compared to single-task situations, leading to dual-task performance costs.

However, Gaspar et al. (2014) were not able to find evidence for different dual-task costs between action video gamers vs. non-gamers. In detail, a simulated street crossing scenario was combined with a working memory task in their dual-task situation. The number of trials on which participants successfully crossed the street and the latency of initiating the crossing were impaired in the dual task compared to performance in the isolated crossing task under single-task conditions. However, there was no reduction of dual-task costs specific for action video gamers. These findings of a lacking dual-task advantage in this group were consistent with those of Donohue et al. (2012) that combined a multiple object tracking task, a paper and pencil search task, and a driving tracking task with answering trivia questions. Although these tasks are certainly relevant in daily life, they are no established measures of dual-task performance and differ considerably from reliable and valid laboratory paradigms.

This conclusion is supported by a number of studies, which showed positive effects of action video gaming on dual-task skills (Chiappe et al. 2013; Strobach et al. 2012a). For example, Strobach et al. (2012a) compared the performance of gamers and non-gamers in dual- and single-task situations including speeded and well-controllable choice RT tasks. There was no difference in single-task RTs between gamers and non-gamers. However, there was a difference in dual tasks: Gamers showed lower RTs and therefore a better performance particularly in dual-task situations compared to non-gamers. This result confirms the assumption of an optimization of executive functions associated with the coordination of two simultaneous tasks. Also, with focus on dual-task performance, non-gamers benefitted from action video game training more than from puzzle training, which indicates a causal link between video game experience and optimized executive functions in dual-task situations (see also Schubert and Strobach 2012). These conclusions were supported from a dual search situation combining an identification and comparison search task (Wu and Spence 2013); performance in this dual-task situation was specifically improved after non-gamers' action video game training vs. puzzle game training.

Updating

Updating and monitoring of representations and information in working memory is another dimension of executive functions (Miyake et al. 2000). In detail, this dimension is related to the monitoring and coding of incoming information that is related to a task at hand. Further, updating processes serve to revise items held in working memory by replacing old information that is no longer relevant with newer, more relevant information. For instance, updating plays an important role in working memory tasks of the *n*-back type, in which a participant is presented with a sequence of stimuli and instructed to indicate when the currently presented stimulus matches the one from *n* steps earlier in the sequence (Jonides and Smith 1997).

Action video gamers show more correct answers than non-gamers in the *n*-back paradigm, which indicates an optimized functionality of the updating function (Colzato et al. 2013). Further, even puzzle game training in non-gamers was effective in producing superior performance in a mental rotation task; transfer in this case is plausible, given that the mental rotation task was both visually and conceptually similar to this training game (Boot et al. 2008). However, in a spatial *n*-back task and a Corsi block-tapping task, no increase in accuracy could be registered, neither in action video gamers vs. non-gamers nor after non-gamers' action game training, strategy game training, and puzzle game training (Boot et al. 2008). In sum, given the current state of the literature in the field, it remains unclear whether there really is a (causal) link between game experience and the executive function updating. By analogy from the many positive transfer findings from the field of updating training (Könen et al. this volume), we assume that one might be moderately optimistic however to find more evidence for an updating transfer as a result of video game experience.

Inhibition

A further executive function is inhibition, which is related to the ability to deliberately inhibit or stop dominant, automatic, or prepotent responses when necessary. A prototypical inhibition task is the color Stroop task (MacLeod 1991). In this task, participants are instructed to respond to the ink of color words; these color words are congruent (e.g., GREEN in green ink) or incongruent (e.g., GREEN in red ink). Typically, RTs in incongruent trials are larger than in congruent trials (i.e., the Stroop effect), indicating the requirement to inhibit or to override the tendency to produce a more dominant or automatic response on naming the color word. However, practice of a Stroop tasks results in a reduction of the Stroop effect within this task, indicating a task-specific training effect by an increased RT reduction in congruent vs. incongruent trials (e.g., Davidson et al. 2003; Wilkinson and Yang 2012).

Given the current state of the literature, we are however skeptical about a positive effect of action video gaming on inhibition. In fact, the Stroop effect was not reduced in participants that played a difficult version of an action video game vs. a non-difficult version of such a game in a study of Engelhardt et al. (2015). This finding demonstrates no evidence for an impact of action video gaming on inhibition. This conclusion is supported in a number of alternative paradigms testing varying facets of inhibition. That is, action video gamers in contrast to non-gamer controls showed no superior performance in a go/no-go task (in this task, participants have to press a button [go] given certain stimuli and inhibit that action under a different set of stimuli [no-go], Oei and Patterson 2014) and in a stop-signal task (in this task, participants are presented with a stimulus prompting them to execute a particular manual response, and this stimulus may or may not be followed by a stop-signal calling for the immediate abortion of that response, Colzato et al. 2013). In sum, at the current state, there is no convincing evidence that experience in action video games may improve executive functioning associated with the inhibition of responses when necessary.

Conclusions

To wrap up the previous sections, we reviewed studies investigating the effect of experience in video games (in particular action video games) on the executive functions shifting, dual tasking, updating, and inhibition. There is evidence that, at least under particular task conditions, strong video game experience may improve the performance in task-switching (i.e., shifting), dual-task situations. Further, preliminary evidence for experience-based improvement in working memory updating exists. In contrast, the literature on effects of action video gaming rather suggests no relation between experience in action video games and improved inhibition.

Let's consider the general mechanism that may explain transfer effects from video gaming to test situation on executive functions. While the introduced version of the "learning to learn" theory predicts a transfer from action video game experience to all types of executive functions (Bavelier et al. 2012), the "common demands" theory rather predicts a specific transfer, depending on similarities between the trained video game and the laboratory task (Oei and Patterson 2015). First, from a more general perspective, there is evidence for transfer effects on shifting, dual tasking, and updating, while there is no such evidence for the case of inhibition. The observation of a different validity of transfer effects is consistent with the "common demands" theory and indicates that switching between different sequential tasks, performing simultaneous tasks, as well as updating information represent relevant demands in (action) video games. In contrast, the inhibition of responses seems to be no essential component in playing these games when applying the logic of the "common demands" theory. This might be surprising given the usual characteristics of action video games. A closer look at these games suggests that the withholding of motor responses and their interruption represent indeed important demands of action video games. Therefore, the fact that currently no valid evidence for effects of action video games on inhibition demands has been reported may be suggestive for two conclusions: it may suggest that the fast interruption and withholding of motor responses is not trainable at all. Alternatively, it may suggest that the current experimental paradigms (i.e., Stroop task, go/no-go task, stop-signal task), which had been used in the past in action video gamers, do not reflect the type of particular inhibition demands inherent to action video games.

Second, from a more detailed perspective, the observation of differential effects of video games on different types of executive functions is also consistent with this theory. For example, there is evidence that puzzle game training, but not action video game training and strategy game training, is able to improve performance in mental rotation (Boot et al. 2008); while the first training type shares common elements with the mental rotation task, the latter ones do not. Further, performance in dual-task situations with speeded, well-controllable component tasks is affected by action video game experience (e.g., Strobach et al. 2012a), while such experience does not seem to affect dual-task situations that are less similar to the gaming environment (e.g., paper and pencil search; Donohue et al. 2012). We are sure that these observations can be complemented with other types of training games and other different functions as well, if a careful analysis is conducted on the type of overlap between training and transfer function.

In sum, we evaluated the existing literature on action video games and executive functions as demonstrating strong evidence for transfers on the executive functions shifting, dual tasking, and updating, while this literature shows no strong evidence for transfer to the inhibition function. However, it is also obvious that each type of executive function requires attempts to replicate existing findings as well as additional analyses in future studies (Colzato and Hommel this volume). These analyses should specify the effects of action video games and other game genres on different executive function types using different experimental paradigms. Preferably, this specification should be realized in the context of training experiments in order to make conclusions about the causal links between game experience and potential changes in executive functioning.

References

Baddeley, A. (1986). *Working memory*. New York, NY: Clarendon Press/Oxford University Press.

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35*, 391–416.

Berryhill, M. E., & Hughes, H. C. (2009). On the minimization of task switch costs following long-term training. *Attention, Perception, & Psychophysics, 71*, 503–514.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129*, 387–398.

Bundesverband Interaktive Unterhaltungssoftware e. V.Gesellschaft für Konsumforschung. (2012). *Gamer in Deutschland*. Retrieved August 17, 2015, from http://www.biu-online.de/de/fakten/marktzahlen/der-deutsche-markt-fuer-computer-und-videospiele-in-der-uebersicht.html

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception, & Psychophysics, 74*(4), 641–647.

Chiappe, D., Conger, M., Liao, J., Caldwell, J., & Vu, K. L. (2013). Improving multi-tasking ability through action videogames. *Applied Ergonomics, 44*(2), 278–284.

Colzato, L. S., van den Wildenberg, W. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research, 77*(2), 234–239.

Colzato, L. S., van Leeuwen, P. J. A., van den Wildenberg, W., & Hommel, B. (2010). DOOM'd to switch: Superior cognitive flexibility in players of first person shooter games. *Frontiers in Psychology, 1*, 8.

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science, 320*(5882), 1510–1512.

Davidson, D. J., Zacks, R. T., & Williams, C. C. (2003). Stroop interference, practice, and aging. *Aging, Neuropsychology, and Cognition, 10*(2), 85–98.

Donohue, S. E., James, B., Eslick, A. N., & Mitroff, S. R. (2012). Cognitive pitfall! Videogame players are not immune to dual-task costs. *Attention, Perception, & Psychophysics, 74*(5), 803–809.

Engelhardt, C. R., Hilgard, J., & Bartholow, B. D. (2015). Acute exposure to difficult (but not violent) video games dysregulates cognitive control. *Computers in Human Behavior, 45*, 85–92.

Gaspar, J. G., Neider, M. B., Crowell, J. A., Lutz, A., Kaczmarski, H., & Kramer, A. F. (2014). Are gamers better crossers? An examination of action video game experience and dual task effects in a simulated street crossing task. *Human Factors, 56*(3), 443–452.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*(6), 756–772.

Green, C. S., Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task-switching. *Computers in Human Behavior, 28*(3), 984–994.

Jonides, J., & Smith, E. E. (1997). The architecture of working memory. In M. D. Rugg (Ed.), *Cognitive neuroscience* (pp. 243–276). Cambridge, MA: The MIT Press.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978–990.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica, 134*(1), 70–78.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*(2), 163–203.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex 'frontal lobe' tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*, 134–140.

Oei, A. C., & Patterson, M. D. (2014). Playing a puzzle video game with changing requirements improves executive functions. *Computers in Human Behavior, 37*, 216–228.

Oei, A. C., & Patterson, M. D. (2015). Enhancing perceptual and attentional skills requires common demands between the action video games and transfer tasks. *Frontiers in Psychology, 6*, 133.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates.

Schubert, T. (2008). The central attentional limitation and executive control. *Frontiers in Bisocience, 13*, 3569–3580.

Schubert, T., & Strobach, T. (2012). Video game experience and optimized executive control skills—On false positives and false negatives: Reply to Boot and Simons (2012). *Acta Psychologica, 141*(2), 278–280.

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*(2), 92–104.

Strobach, T., Frensch, P., Müller, H., & Schubert, T. (2015). Evidence for the acquisition of dual-task coordination skills in older adults. *Acta Psychologica, 160*, 104–116.

Strobach, T., Frensch, P. A., & Schubert, T. (2012a). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*(1), 13–24.

Strobach, T., Liepelt, R., Schubert, T., & Kiesel, A. (2012b). Task switching: Effects of practice on switch and mixing costs. *Psychological Research, 76*(1), 74–83.

Strobach, T., Salminen, T., Karbach, J., & Schubert, T. (2014). Practice-related optimization and transfer of executive functions: A general review and a specific realization of their mechanisms in dual tasks. *Psychological Research, 78*(6), 836–851.

Szameitat, A. J., Lepsien, J., von Cramon, D., Sterr, A., & Schubert, T. (2006). Task-order coordination in dual-task performance and the lateral prefrontal cortex: An event-related fMRI study. *Psychological Research, 70*(6), 541–552.

Wilkinson, A. J., & Yang, L. (2012). Plasticity of inhibition in older adults: Retest practice and transfer effects. *Psychology and Aging, 27*(3), 606–615.

Wu, S., & Spence, I. (2013). Playing shooter and driving videogames improves top-down guidance in visual search. *Attention, Perception, and Psychophysics, 75*(4), 673–686.

Mindfulness and Meditation Training

Paul Verhaeghen

Introduction

Acquiring a skill is often a straightforward process: Repeat a task many, many times, and over time its component skills will most likely be performed with increased efficiency. This process is often done deliberately (e.g., in music practice), but sometimes the skill training is much more hidden. This chapter is about one of such hidden trainings: How meditation (more specifically mindfulness meditation) is a form of attention training.

Mindfulness Meditation as Attention Training

Typically, mindfulness meditation practices fall into two main categories or styles. In the first, *focused-attention meditation*, the meditator focuses her mind on a single object—often the breath—unwaveringly and clearly. The goal is to calm the mind and to teach it to stay a particular course for a long period of time, thus practicing both controlled and sustained attention. Practicing focused-attention meditation also implies monitoring the mind, that is, to continuously check for distractions. When distractions arise, the meditator simply meets them with patience and kindness and then returns to the object of concentration. In the second style, *open-monitoring meditation*, awareness is applied to whatever is present in experience—an emotion, a percept, a memory, a thought—as it arises moment to moment; the meditator simply observes this presence. Along the way, the meditator learns to cultivate "reflexive awareness," that is, awareness that refers back on itself.

P. Verhaeghen (✉)
School of Psychology, Georgia Institute of Technology, Atlanta, GA, USA
e-mail: paul.verhaeghen@psych.gatech.edu

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_12

The end goal of these practices is not to train attention per se (for an overview of such work, see Karbach and Kray this volume), but to learn to apply careful and open, nonjudgmental attention (e.g., Kabat-Zinn 1990) to one's perceptions in order to see their impermanence and to ultimately transcend the sense of self. However, one can argue that the process of practice by itself produces an exquisite form of skill training.

How focused-attention practice can hone attentional skill is nicely illustrated in a study by Hasenkamp et al. (2012). In this study, 14 seasoned meditators (with on average 1400 h of lifetime practice) meditated inside the scanner for 20 min, focusing on the breath. They pressed a button as soon as they realized that their mind had wandered away. The researchers used an event-related design centered on 3-s slices defined in reference to the button press. In a 3 s time window before the button press—when meditators were presumably mind-wandering—many regions of the default-mode network were activated, as one would expect. In the 3 s around the button press—when meditators became aware of their mind-wandering—the insula and the anterior cingulate cortex, regions associated with the salience attention network, were activated. The 3-s slice after that—when participants were switching their attention back to the breath—was associated with activation in the executive attention network (the lateral prefrontal cortex and the inferior parietal lobe). One intriguing finding was how often this cycle repeated: On average, meditators pressed the button 15.5 times over the course of 20 min. Thus, over the course of their 1400 h of lifetime experience, Hasenkamp's meditators must have gone through 63,000 cycles of activating first the salience and then the executive attention networks in response to default-mode activation.

Meditation and Attention in the Brain

Hasenkamp's study is not the only study finding brain activation in attention centers during meditation. The largest meta-analysis on the topic (Tomasino et al. 2013) collected the results from 26 studies, reporting on a total of 313 meditators, with on average 11,552 lifetime hours of meditation experience. The main result was that meditators, while meditating, activate both parts of the salience network (the insula) and the executive attention network (the superior and inferior parietal lobe). Note that the inferior parietal lobe acts as a switch between the executive control network and the default network (Spreng et al. 2013). Activation in this brain region might then mean that meditators are not just focusing their attention on the object of their meditation but are also actively suppressing activation of the default-mode network. This assumption is confirmed in the finding that parts of the default-mode network (the angular gyrus, the middle temporal gyrus, and the precuneus) quiet down during meditation.

Further corroboration of the hypothesis that meditation impacts attention comes from functional connectivity research. Three studies (Brewer et al. 2011; Froeliger et al. 2012; Josipovic et al. 2012) found heightened functional connectivity between at least one part of the default-mode networks and at least one part of the attention network during meditation, compared to the couplings when participants were resting in the scanner. This suggests that meditators stay on task while meditating: When the default-mode network is active—that is, when the mind strays from its focus—the attention system notices, clamps down, and corrects. This tighter coupling during meditation reinforces the main point of Hasenkamp's study, namely, that focused-attention meditation really is a predictable dynamic process, a series of cycles that occur in a consistent manner.

Finally, the one extant meta-analysis on brain morphology and meditation (Fox et al. 2014; 21 studies comparing a total of 503 meditators with on average 4664 h of expertise with 472 non-meditators) found changes in brain morphology consistent with changes in attentional proficiency. First, meditators had higher gray matter volume and/or density in parts of the salience network (the anterior cingulate cortex and the insula), as well as in parts of the executive network (the rostrolateral prefrontal cortex). Second, major parts of the default-mode network (the posterior parietal cortex and the precuneus) were lower in volume and/or density in meditators than non-meditators.

Fox et al. (2014) also identified differences in two white-matter pathways. First, meditators have increased information transfer between the anterior parts of the two hemispheres, as suggested by an enlarged forceps minor and genu of the corpus callosum, perhaps a by-product of activation in frontal areas during meditation (such as the insula, the anterior cingulate, the rostrolateral prefrontal cortex, and the orbitofrontal cortex). Second, meditators have a more efficient superior longitudinal fasciculus. The different subcomponents of this tract are responsible for the sense of the body in space, the moment-to-moment understanding of the state of the body itself, spatial attention, and control over the focus of attention (Makris et al. 2005). This enhanced connection might then be the fruit of repeatedly and persistently paying close attention to fleeting sensations in the body (i.e., the breath and/or bodily sensations).

There is some evidence that changes in gray matter volume in the salience attention network accrue over time. One study reports a correlation between meditation experience and volume/density in the anterior cingulate of .32 (averaged over two subregions; Grant et al. 2010). The average correlation between experience and volume/density in the insula is .25 (Hölzel et al. 2011; Luders et al. 2012). Data are more disappointing with regard to the executive control network: The single study that analyzed the correlation between meditation experience and volume/density of the rostrolateral prefrontal cortex failed to find one; nothing is known about the precuneus and the posterior cingulate cortex.

Note that all these data are correlational and hence cannot give a definitive answer about the causal direction.

Meditation and Its Effects on Psychological Aspects of Attention

The largest meta-analysis on the psychological effects of meditation (Sedlmeier et al. 2012) gathered 22 studies (total sample size of 1307) relevant to attention (operationalized as concentration/attention, sustained attention, orienting, alerting, conflict monitoring, executive processing, and behavioral inhibition). All these studies compared performance of a group of meditators (most of them fresh out of an 8-week mindfulness-based stress reduction (MBSR) type program) with a control group of non-meditators. The average effect in these studies was a mean standardized difference (MSD) of 0.58, implying that the average meditator is more attentive than 72 % of non-meditators.

It makes sense to delve a little deeper here and detail the results in terms of different aspects of attention. I will review three, closely tied to the cycle of meditation as found by Hasenkamp et al. (2012): control over attention, alerting, and sustained attention.

Meditation and Control over Attention

Most studies on the effects of mindfulness and meditation on attention have focused on changes in attentional control. I located nine studies on the effects of meditation and mindfulness practice on the Stroop test (Allen et al. 2012; Anderson et al. 2007; Chan and Woollacott 2007; Jensen et al. 2012; Kozasa et al. 2012; Lykins and Baer 2009; Moore et al. 2012; Moore and Malinowski 2009; Teper and Inzlicht 2013); the total number of meditators involved was small—221. The average effect size for these eight studies was MSD = 0.45.[1]

In three of the nine studies, participants were new meditators who learned to meditate during the study, accumulating between 18 and 40 h of experience; the average effect size for these studies was MSD = 0.42. The other studies compared seasoned meditators with non-meditators; this resulted in a very similar effect size, namely, MSD = 0.48. The similarity in effect sizes for these two groups suggests two things. First, even 40 or so hours of practice already result in measurable changes in control over attention. Second, the number of years of accumulated practice may be less important than the amount of daily practice. Consistent with this view, one study (Teper and Inzlicht 2013) did find that although the number of years of meditation experience correlated (rather modestly) with the Stroop effect ($r = -.27$), so did meditation frequency ($r = -.23$). (The first correlation can be explained by the fact that more seasoned meditators tend to spend more time on

---

[1] All effect sizes are reported such that a positive effect indicates that the hypothesis of better attention in meditators is confirmed; in the case of Stroop, a positive effect size would thus indicate that meditators have a smaller Stroop effect.

the cushion.) Another study (Chan and Woollacott 2007) found a dose–response relationship with the number of minutes practiced per day ($r = -.17$), but not with total hours of lifetime meditation experience.

I was able to locate five studies on attentional control measures other than Stroop (Allen et al. 2012; Heeren et al. 2009; Jensen et al. 2012; Jha et al. 2007; Sahdra et al. 2012); these yielded an average effect size of MSD = 0.23. Allen et al. also found a strong correlation ($r = .52$) between the number of minutes practiced over the last 8 weeks and how good people are at not making errors on a go/no-go task.

Combining all ten papers that included measures of attentional control, the average effect size of meditation on attentional control was MSD = 0.39, a lower number than reported in the Sedlmeier et al. meta-analysis, but still sizeable.

Meditation and Nonjudgmental Alerting

Studies that have looked at meditation and alerting all center around Kabat-Zinn's (1990) concept of nonjudgmental alerting, that is, taking a nonreactive stance toward whatever presents itself to the attentional field.

One set of studies considered attentional blink and meditation (Slagter et al. 2007; van Leeuwen et al. 2009; van Vugt and Slagter 2014). In the attentional blink task, participants see a stream of 20 or so letters, presented at about 10 items per second. One or two digits are intermingled with the letters; participants press a button whenever they spot a digit. When the stream contains two digits, subjects often miss the second digit when it is shown within 500 ms of the first one. The standard explanation is that detecting the second digit is only possible if enough resources are available; this requires the subject to relinquish attention as soon as the first digit has been detected. In two studies that compared the attentional blink effect in long-term practitioners with that in novices, the average effect size was MSD = 0.65. One of these two studies also compared attentional blink before and after a 3-month retreat; the effect size for this comparison was MSD = 0.38 in beginning meditators and MSD = 1.17 in advanced meditators. Another finding is that the attentional blink effect is smaller during open-monitoring meditation than during focused-attention meditation, at least in highly experienced meditators, as one would expect if the decrease in attentional blink signals an increase in openness and nonreactivity (van Vugt and Slagter 2014).

Other paradigms confirm this lower reactivity of meditators.

One study (Hodgins and Adair 2010) used the infamous gorilla–basketball video and found that meditators were 50 % more likely to spot the interloping gorilla than non-meditators. At the same time, meditators were also about twice as accurate in keeping count of the passes, suggesting that they were able to both focus and be open-minded at the same time.

Another study (Van den Hurk et al. 2010) used a bimodal startle-type task. Participants stood in front of a screen. At one point, a light turned on either to the left or the right; participants were asked to turn their head toward the light as fast as possible. Participants typically speed up when the light is accompanied by a centrally presented uninformative sound; this is likely an arousal effect. Meditators were less likely to speed up than non-meditators, suggesting that they process the sound without attaching a startling, arousing quality to it—it is just a loud noise.

Yet another study that demonstrates that meditators may have lower reactivity is an ERP Stroop study (Teper and Inzlicht 2013). The researchers were interested in error-related negativity (ERN) and error-related positivity (Pe). The ERN occurs about 100 ms after making an incorrect response, and it likely originates from the anterior cingulate, a part of the salience attention network. The Pe occurs a little later, about 200 ms after making an error, and it originates likely in the posterior cingulate, which is part of the core of the default-mode network; the Pe signifies awareness of the error. The researchers found a larger ERN effect in meditators than in non-meditators; both years and frequency of meditation correlated with ERN ($r = .37$ and .35, resp.), showing that meditators' brains are more alert to the mistakes they make. Interestingly, meditators did not show larger Pe values; thus, their increased sensitivity to errors does not lead to stronger awareness of errors. One possible interpretation is that even though a meditator's brain quickly realizes its mistakes, it is also very quick to let go of that reaction.

In a fourth study, van Leeuwen and colleagues (2012) showed students a series of local–global stimuli—larger digits formed out of smaller digits. Participants pressed a button whenever they saw the digit 1 or 2, regardless of whether it was the global (large) or local (small) digit in the figure. Typically, subjects respond faster to global digits than local digits—in this study the difference was 56 ms. The study also included eight Buddhist monks and nuns; these showed less of a global bias—the difference was only 21 ms. This suggests that meditators have more openness to what is really there (viz., two different digits). ERP analysis also demonstrated that the meditators had stronger P1 and N1 responses, suggesting a quicker uptake of information; they also showed larger engagement in the attention networks that are typically implicated in this task.

This quicker uptake of information is confirmed in studies that directly examined perceptual thresholds. Jensen and colleagues (2012) had participants perform attention tasks before and after a standard 8-week MBSR program. Before training, the perceptual threshold for identifying a single letter was 15 ms; after MBSR training, this was 9 ms. Likewise, MacLean et al. (2010) tested seasoned meditators before, during, and after a 3-month retreat on line-length discrimination and compared their performance with that of a no-retreat control group of equally seasoned meditators. Retreatants and non-retreatants did not differ in discrimination thresholds before the retreat, but retreatants were able to detect smaller differences between the lines both at the halfway point of the retreat and at the end of the retreat, as well at a follow-up session 5 months after the end of the retreat. There was a dose–response relationship: Those who spent more time in daily meditation during the after-retreat period could detect smaller differences between the two lines ($r = .36$).

Meditation and Sustained Attention

Maybe surprisingly, there is not a lot of research on meditation and sustained attention. I found seven relevant studies (Anderson et al. 2007; Banks et al. 2015; Jha et al. 2015; MacLean et al. 2010; Morrison et al. 2013; Mrazek et al. 2013; Sahdra et al., 2011); these yielded an average effect size of MSD = 0.39. Five of these studies used novices going through MBSR or an MBSR-like program; the average effect size was MSD = 0.33. The two studies that compared seasoned meditators before and after a 3-month retreat where the participants meditated for about 500 h had an average effect size of MSD = 0.60, suggesting that an intense period of practice leads to an increased ability to sustain attention. Only one of the studies looked at the dose–response relationship; it did not find one.

I want to single out one additional study, by Carter et al. (2005), that used two rather exceptional tasks to measure stability of attention. The research team traveled all the way to the Himalayan mountains in Ladakh to test Tibetan Buddhist monks living in exile there. The first task was a binocular rivalry task. Binocular rivalry refers to the curious sensation that happens when participants are presented with two different stimuli, one presented to each eye (e.g., the right eye sees a house, the left eye sees a face): The two images tend to alternate in awareness every few seconds. Carter found that focused-attention meditation led to slower alterations (i.e., more stability) in over half of the monks, both during and right after meditation. The second task was a motion-induced blindness task. Participants saw a video of a blinking green dot at the center of a computer screen, which also has three stationary yellow dots arranged in a triangle closer to the edge of the screen, and a lattice of rotating crosses. With sustained attention, awareness of the yellow dots disappears after about 10 s, but the dots reappear as soon as attention is relaxed or eye movements are made. The average student volunteer was able to keep the three dots from reappearing for 2.6 s. The average monk was able to do this for 4.1 s or about 50 % longer. More importantly, the duration record in the group of students was 6 s; 10 out of 76 monks equaled or beat that record—one monk was able to stabilize the image for 128 s and one even for 723 s.

Meditation and Attention: Conclusions

Meditation has an effect on all three forms of attention reviewed here: Its effect on controlled attention is around 0.4 SD; a similar effect is noted on sustained attention, and there are also consistent effects on nonjudgmental alerting, with an effect size of 0.65 SD for attentional blink studies.

The most intriguing result is the evidence for nonjudgmental alerting, arguably a key component in the concept of mindfulness, as seen in the attentional blink task, the gorilla video task, the (non)startle effect, the local–global effect, and in brain parameters like error-related negativity and positivity. This is also interesting because this form of openness or receptiveness is an aspect of attention that is often undervalued, to say the least, in standard cognitive psychology, which is much more concerned with the amount or acuity of attention rather than its quality. The present studies show that open-mindedness is a skill that operates in a process as basic as paying attention. It also demonstrates that this skill can be trained. Two studies even suggest that meditation practice can help lower the threshold of perception, literally letting more of the outside world enter the realm of awareness.

Attention is often considered the gateway to other aspects of cognition. Particularly, attention is important for working memory, helps with knowledge retrieval, and is important for real-life aspects of cognition. All of these aspects of cognition indeed benefit from meditation and mindfulness training (Verhaeghen in press), although the number of studies and the number of participants involved in each of these studies are still too small to comfortably allow for definitive conclusions. These findings suggest that meditation may lead to a cognitive cascade where meditation leads to changes in attention, which in turn positively influences other aspects of cognition.

Finally, attention-and-meditation studies underscore the importance of frequency or amount of meditation rather than accumulated hours of practice. Frequent practice appears to sharpen the focus of attention, to make one more alter to mistakes, to broaden the limits of perception, and to increase sustained attention. The finding that 8-week MBSR programs can have a meaningful impact on attention, often on par with the effects seen in very seasoned meditators, further underscores this point.

References

Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of Neuroscience, 32*, 15601–15610.

Anderson, N. D., Lau, M. A., Segal, Z. V., & Bishop, S. R. (2007). Mindfulness-based stress reduction and attentional control. *Clinical Psychology and Psychotherapy, 14*, 449–463.

Banks, J. B., Welhaf, M. S., & Srour, A. (2015). The protective effects of brief mindfulness meditation training. *Consciousness and Cognition, 33*, 277–285.

Brewer, J. A., Worhunsky, P. D., Gray, J. R., Tang, Y. Y., Weber, J., & Kober, H. (2011). Meditation experience is associated with differences in default mode network activity and connectivity. *Proceedings of the National Academy of Sciences, 108*, 20254–20259.

Carter, O. L., Presti, D. E., Callistemon, C., Ungerer, Y., Liu, G. B., & Pettrigrew, J. D. (2005). Meditation alters perceptual rivalry in Tibetan Buddhist monks. *Current Biology, 15*, R412–R413.

Chan, D., & Woollacott, M. (2007). Effects of level of meditation experience on attentional focus: Is the efficiency of executive or orientation networks improved? *Journal of Alternative and Complementary Medicine, 13*, 651–658.

Fox, K. C., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., & Christoff, K. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience and Biobehavioral Reviews, 43*, 48–73.

Froeliger, B., Garland, E. L., Kozink, R. V., Modlin, L. A., Chen, N. K., McClernon, F. J., & Sobin, P. (2012). Meditation-state functional connectivity (msFC): Strengthening of the dorsal attention network and beyond. *Evidence-Based Complementary and Alternative Medicine: eCAM, 2012*, 680407.

Grant, J., Courtemanche, J., Duerden, E. G., Duncan, G. H., & Rainville, P. (2010). Cortical thickness and pain sensitivity in zen meditators. *Emotion, 10*, 43–53.

Hasenkamp, W., Wilson-Mendenhall, C. D., Duncan, E., & Barsalou, L. W. (2012). Mind wandering and attention during focused meditation: A fine-grained temporal analysis of fluctuating cognitive states. *NeuroImage, 59*, 750–760.

Heeren, A., Van Broeck, N., & Philippot, P. (2009). The effects of mindfulness on executive processes and autobiographical memory specificity. *Behaviour Research and Therapy, 47*, 403–409.

Hodgins, H. S., & Adair, K. C. (2010). Attentional processes and meditation. *Consciousness and Cognition: An International Journal, 19*, 872–878.

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., et al. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research: Neuroimaging, 191*, 36–43.

Jensen, C., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness training affects attention—Or is it attentional effort? *Journal of Experimental Psychology: General, 141*, 106–123.

Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective and Behavioral Neuroscience, 7*, 109–119.

Jha, A. P., Morrison, A. B., Dainer-Best, J., Parker, S., Rostrup, N., & Stanley, E. A. (2015). Minds "at attention": Mindfulness training curbs attentional lapses in military cohorts. *PLoS One, 10*, e0116889.

Josipovic, Z., Dinstein, I., Weber, J., & Heeger, D. J. (2012). Influence of meditation on anti-correlated networks in the brain. *Frontiers in Human Neuroscience, 5*, 183.

Kabat-Zinn, J. (1990). *Full catastrophe living: The program of the stress reduction clinic at the University of Massachusetts Medical Center*. New York: Delta.

Karbach, J., & Kray, J. (this volume). Executive functions. In T. Strobach, J. Karbach (Eds.), *Cognitive training: An overview of features and applications*. New York: Springer.

Kozasa, E. H., Sato, J. R., Lacerda, S. S., Barreiros, M. A., Radvany, J., Russell, T. A., & Amaro, E. (2012). Meditation training increases brain efficiency in an attention task. *NeuroImage, 59*, 745–749.

Luders, E., Kurth, F., Mayer, E. A., Toga, A. W., Narr, K. L., & Gaser, C. (2012). The unique brain anatomy of meditation practitioners: alterations in cortical gyrification. *Frontiers in Human Neuroscience, 6*, 34.

Lykins, E. L. B., & Baer, R. A. (2009). Psychological functioning in a sample of long-term practitioners of mindfulness meditation. *Journal of Cognitive Psychotherapy, 23*, 226–241.

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., et al. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science, 21*, 829–839.

Makris, N., Kennedy, D. N., McInerney, S., Sorensen, A. G., Wang, R., Caviness, V. S., & Pandya, D. N. (2005). Segmentation of subcomponents within the superior longitudinal fascicle in humans: A quantitative, in vivo, DT-MRI study. *Cerebral Cortex, 15*, 854–869.

Moore, A. W., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience, 6*, 18.

Moore, A., & Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness and Cognition: An International Journal, 18*, 176–186.

Morrison, A. B., Goolsarran, M., Rogers, S. L., & Jha, A. P. (2013). Taming a wandering attention: Short-form mindfulness training in student cohorts. *Frontiers in Human Neuroscience, 7*.

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness training improves working memory capacity and GRE performance while reducing mind wandering. *Psychological Science, 24*, 776–781.

Sahdra, B. K., MacLean, K. A., Ferrer, E., Shaver, P. R., Rosenberg, E. L., Jacobs, T. L., & Saron, C. D. (2011). Enhanced response inhibition during intensive meditation training predicts improvements in self-reported adaptive socioemotional functioning. *Emotion, 11*, 299–312.

Sedlmeier, P., Eberth, J., Schwarz, M., Zimmermann, D., Haarig, F., Jaeger, S., & Kunze, S. (2012). The psychological effects of meditation: A meta-analysis. *Psychological Bulletin, 138*, 1139–1171.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., & Nieuwenhuis, S. (2007). Mental training affects distribution of limited brain resources. *PLoS Biology, 5*, 138.

Spreng, R. N., Sepulcre, J., Turner, G. R., Stevens, W. D., & Schacter, D. L. (2013). Intrinsic architecture underlying the relations among the default, dorsal attention, and frontoparietal control networks of the human brain. *Journal of Cognitive Neuroscience, 25*, 74–86.

Teper, R., & Inzlicht, M. (2013). Meditation, mindfulness and executive control: The importance of emotional acceptance and brain-based performance monitoring. *Social Cognitive and Affective Neuroscience, 8*, 85–92.

Tomasino, B., Fregona, S., Skrap, M., & Fabbro, F. (2013). Meditation-related activations are modulated by the practices needed to obtain it and by the expertise: An ALE meta-analysis study. *Frontiers in Human Neuroscience, 6*, 346.

Van den Hurk, P. M., Giommi, F., Gielen, S. C., Speckens, A. M., & Barendregt, H. P. (2010). Greater efficiency in attentional processing related to mindfulness meditation. *Quarterly Journal of Experimental Psychology, 63*, 1168–1180.

van Leeuwen, S., Müller, N. G., & Melloni, L. (2009). Age effects on attentional blink performance in meditation. *Consciousness and Cognition, 18*, 593–599.

van Leeuwen, S., Singer, W., & Melloni, L. (2012). Meditation increases the depth of information processing and improves the allocation of attention in space. *Frontiers in Human Neuroscience, 6*.

van Vugt, M. K., & Slagter, H. A. (2014). Control over experience? Magnitude of the attentional blink depends on meditative state. *Consciousness and Cognition, 23*, 32–39.

Verhaeghen, P. (in press). *Presence: How meditation and mindfulness shape mind, brain, and life*. New York: Oxford University Press.

Music Training

Swathi Swaminathan and E. Glenn Schellenberg

Introduction

Over the last two decades, researchers have examined whether taking music lessons has a positive influence on nonmusical cognitive abilities. Such an influence would represent a form of *transfer*. The most common design (i.e., correlational) involves comparing musically trained and untrained individuals, which makes it impossible to determine whether music lessons are the cause rather than consequence of improved cognitive performance. True experiments with random assignment are relatively rare because they are costly and because attrition limits the possibility of long-term studies. Although strong associations are often reported, experimental studies tend to yield small effects or results that are limited in scope (for reviews see Schellenberg and Weiss 2013; Swaminathan and Schellenberg 2014). In the present chapter, we review studies published since 2000, with an emphasis on those that allow for inferences of causation. We highlight five issues that future research could seek to clarify (1) whether transfer effects are domain general or domain specific, (2) mechanisms of transfer, (3) characteristics of the music program, (4) characteristics of the trainee, and (5) the sociocultural context.

Domain-General or Domain-Specific Transfer?

One long-standing question asks whether music lessons have putative effects that transfer to *specific* cognitive domains (e.g., visuospatial skills, language) or whether they might enhance domain-*general* cognitive abilities, such as executive functions

---

S. Swaminathan • E.G. Schellenberg (✉)
Department of Psychology, University of Toronto Mississauga,
Mississauga, ON, Canada
e-mail: swathi.swaminathan@mail.utoronto.ca; g.schellenberg@utoronto.ca

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_13

and intelligence. Correlational evidence documents that musically trained individuals exhibit advantages relative to their untrained counterparts on a wide variety of visuospatial tasks (for review, see Schellenberg and Weiss 2013). Longitudinal and experimental results offer a less consistent picture. For example, one study examined high-risk children from families with low socioeconomic status who were having difficulties in school (Portowitz et al. 2009). The children were enrolled in remedial programs at four different after-school centers. Three of these incorporated a two-year music enrichment program, which included 2–3 h per week of music listening, individual instrumental lessons, and group performances. Compared to children at the center without the program, children who received the intervention showed larger improvements in the ability to remember and copy a complex line drawing. Nevertheless, *nonmusical* programs of similar intensity may have a similar effect, and randomization of centers rather than individuals raises the possibility that other differences among centers may have played a role. Moreover, in another study that compared an intensive, 4-week, computerized, music listening program to a similar program in visual art (Moreno et al. 2011), improvement from pre- to posttest on block design (i.e., a visuospatial subtest from the Wechsler IQ tests) did not differ between the two groups of children.

Other scholars argue for extensive connections between music training and language skills. Relevant theories suggest that mental processes for music and language overlap (e.g., Kraus and Chandrasekaran 2010; Patel 2011), which implies that linguistic rather than visuospatial skills are most likely to improve from music training. In line with this view, music training is correlated with a wide range of speech skills (for review, see Schellenberg and Weiss 2013), including linguistic stress processing, the perception of intonation in speech, speech segmentation, and phonological perception. It is unclear why musicians are better than nonmusicians at perceiving speech in noise in some instances (e.g., Parbery-Clark et al. 2009) but not in others (e.g., Ruggles et al. 2014). Musically trained individuals also show advantages on higher-level language tests such as those that measure verbal short-term, long-term, and working memory, vocabulary, reading, and acquisition of a second language (for review, see Schellenberg and Weiss 2013).

Despite the fact that reported associations extend to speech, language, and reading, evidence for causation is limited. For example, in one instance, improvements on a brief test of vocabulary (Moreno et al. 2011) were larger among children who took 4 weeks of daily training in music listening compared to children who took a similar amount of training in visual arts. In another instance, 6 months of music or painting training led to larger improvements in pronouncing irregularly spelled words among children taking the music lessons (Moreno et al. 2009). Two other experimental studies found that phonological awareness was enhanced after music training (Degé and Schwarzer 2011; Flaugnacco et al. 2015). In sum, associations between music training and language abilities are well documented, and it seems likely that music training plays a causal role. Nevertheless, experimental evidence that allows for unambiguous causal inferences is limited to outcome variables that measured very narrow aspects of reading or language use (e.g., phonological awareness).

If music training is associated with both visuospatial *and* language skills, might variance in all three domains (music, visuospatial, and language) be a consequence of general cognitive abilities? Or does music training have widespread transfer effects that influence such abilities, which include intelligence and executive functions? General cognitive improvements could manifest as improvements in specific cognitive abilities whether or not they are attributable to music lessons.

Correlational evidence confirms that musically trained children and adults often have substantially higher IQ scores than their untrained counterparts and that additional music training predicts larger IQ advantages (for review, see Schellenberg and Weiss 2013). Experimental evidence from three different countries also indicates that music lessons may cause small improvements in IQ scores. For example, when Canadian 6-year-olds were randomly assigned to one year of music lessons (keyboard or voice) or to control conditions (drama or no lessons at all), larger pre- to posttest improvements in IQ were evident in the two music groups compared to the two control groups (Schellenberg 2004). In another study of Iranian preschoolers, children assigned to three months of weekly music lessons had larger gains in IQ compared to a control group with no lessons (Kaviani et al. 2014). In a third study of Israeli children, improvements in IQ were greater among children exposed to an enriched program in music, compared to control children without such a program (Portowitz et al. 2009). Although the generality across cultures is reassuring, it is not clear from the Iranian and Israeli results whether the increase in IQ scores was a consequence of *music training* per se, because the control groups had no comparable, nonmusical experience (i.e., there was no “active” control group; Schmiedek this volume), which means that other aspects of the music programs may have contributed to the findings. In short, convincing evidence that music training causes small increases in IQ comes from a single study.

Even in correlational studies, music training sometimes has only a marginal or no association with IQ (Schellenberg and Moreno 2010). For example, null or mixed results often occur when highly trained musicians are compared with individuals who have similar amounts of nonmusical training or education (e.g., Brandler and Rammsayer 2003; Helmbold et al. 2005). Moreover, in a recent study, preschool children were assigned to either 6 weeks of group music lessons or no lessons at all (Mehr et al. 2013). The music training had no reliable effects on cognitive abilities. In this instance, however, the children may have been too young for music lessons, or the training may have been too brief (4.5 h total).

In any event, the available findings make it difficult to attribute most of the effects observed in correlational studies to music lessons, because (1) one would expect such effects to be particularly reliable among individuals with the greatest amount of training, and (2) effect sizes from actual experiments are much smaller than those that are typically reported in correlational studies. A simpler explanation is that children who take music lessons, and adults who took music lessons in childhood, differ from other individuals in multiple ways, including cognitive abilities, personality, and demographic variables. In some instances, however, music training may exaggerate individual differences that were present before the lessons began.

Mechanisms of Transfer

The focus of much research to date has involved identifying associations between music training and high-level cognitive abilities, but it is unclear why such associations would emerge (Colzato and Hommel this volume; Taatgen this volume). One possibility is that music lessons train executive functions, including working memory, which in turn promote general cognitive enhancements (e.g., Alloway et al. this volume; Karbach and Kray this volume; Schellenberg and Peretz 2008). On this view, transfer occurs when executive functions are improved during the course of music training. Indeed, in some instances, musically trained individuals outperform their untrained counterparts on auditory and nonauditory tests measuring executive functions (Roden et al. 2014; Zuk et al. 2014), and, in one case, the association between music training and IQ appeared to be completely mediated by executive functions (Degé et al. 2011). In another instance, however, music training was associated with IQ but not with executive functions except for working memory (Schellenberg 2011). Thus, it is still an open question whether the association between music training and general cognitive ability is mediated by executive functions.

Other researchers suggest that music lessons train the auditory brainstem to make high-fidelity copies of auditory (including speech) stimuli (Kraus and Chandrasekaran 2010). These subcortical changes are correlated with speech and higher-level language skills including reading and are thought to mediate the language benefits of music training. In line with this hypothesis, musically trained individuals exhibit more precise brainstem responses to speech stimuli (Strait et al. 2014), and brainstem responses become more precise after music training (Kraus et al. 2014). It remains to be seen whether brainstem responses actually mediate any associations between music lessons and language.

Another view holds that overlap between language and music abilities occurs primarily in the temporal domain (Goswami 2012; Tallal and Gaab 2006), which implies that *rhythm*-based music interventions are most likely to be effective in training language skills. Evidence consistent with this theory comes from a study of children with dyslexia who were assigned to 6 weeks of auditory rhythm training, a commercially available phoneme discrimination intervention, or to a control group (Thomson et al. 2013). Compared to the control group, the rhythm and phoneme groups improved more on tests of phonological processing over the course of the study. Moreover, in typically developing children, rhythm-perception abilities are associated positively with grammatical abilities (Gordon et al. 2015).

A final mechanistic explanation comes from the OPERA hypothesis (Patel 2011). It posits that music lessons train speech skills when five conditions are met: (1) the speech skill shares a neural overlap (*O*) with a music skill, (2) the music skill involves particularly precise (*P*) auditory processing, (3) the music training has positive emotional (*E*) consequences, (4) the lessons involve repetition (*R*), and (5) the lessons require focused attention (*A*). This theory is largely untested, and it is unclear whether these five conditions are necessary and sufficient for transfer and/or whether transfer is contingent on all five conditions being met.

Future research could focus on evaluating and comparing the existing theoretical approaches, as well as on constructing new theories that generate empirically testable hypotheses. Theoretical multiplicity will undoubtedly promote debate and growth in the field.

Characteristics of the Music Training Program

Private and small group music lessons emphasize individual accomplishment and skill mastery. Larger, group-based lessons, by contrast, are more likely to emphasize collective outcomes. It is therefore possible that private music training is more effective than group-based lessons at improving scores on tests of cognitive ability, which by definition measure individual ability and accomplishment. Indeed, a recent longitudinal study of group-based music lessons found that advantages emerged only after extended training (Slater et al. 2015). Specifically, after 2 years of lessons, children demonstrated improved performance on a test that measured the ability to perceive speech in the midst of background noise. A separate group of children, who received 1 year of the same lessons, did not show improvement on the same test.

Other experimental studies with individual lessons or lessons taught in small groups have found advantages even with shorter-term interventions, such as when lessons are taught daily for 2 weeks (Moreno et al. 2011), daily for 20 weeks (Degé and Schwarzer 2011), weekly for 36 weeks (Schellenberg 2004; Thomson et al. 2013), or twice weekly for 30 weeks (Flaugnacco et al. 2015). It is important to note, however, that in the short-term studies with daily training, the lessons focused primarily on music listening rather than learning to play an instrument. In other words, music lessons may be more likely to improve language-related outcomes if the lessons emphasize listening skills. Language benefits could also be more likely if the lessons target rhythm skills (Flaugnacco et al. 2015; Thomson et al. 2013). In any event, many successful music interventions adopted nonstandard pedagogies (Degé and Schwarzer 2011; Flaugnacco et al. 2015; Moreno et al. 2011; Thomson et al. 2013). Thus, future research could compare the effects of different kinds of music training.

Characteristics of the Trainee

Music training is correlated with cognitive skills in some samples of individuals but not in others (see Katz et al. this volume). As noted, highly trained musicians often do not show an IQ advantage compared to equally qualified individuals in nonmusical domains (Brandler and Rammsayer 2003; Helmbold et al. 2005). Thus, the association with general cognitive abilities may emerge primarily when music training is an additional activity rather than an individual's primary focus.

Other findings suggest that the association between music lessons (or musical involvement) and cognitive ability may be explained by personality factors, particularly the dimension called “openness to experience” (Corrigall et al. 2013; Corrigall and Schellenberg 2015), which is characterized by curiosity, intellectual engagement, and aesthetic sensitivity. These findings imply that musically trained individuals may perform well on intelligence tests because they tend to be particularly interested in learning new things, including music. Moreover, common genetic factors appear to underlie intelligence *and* the propensity to practice music (Mosing et al. 2015). In short, correlations between music training and cognitive ability may stem from preexisting differences. When considered jointly with evidence for small cognitive benefits of music training (e.g., Schellenberg 2004), it is likely that some individuals benefit more than others from music lessons. More generally, the study of music training and transfer is well suited to exploring gene-environment interactions (Schellenberg 2015). Future research could consider how preexisting trainee characteristics interact with music training to influence cognitive outcomes.

The Sociocultural Context

The issue of transfer effects from music training to nonmusical cognitive skills has practical implications. For example, music interventions may provide an enjoyable way for children with dyslexia to improve certain reading-related skills (Flaugnacco et al. 2015; Thomson et al. 2013). The study of transfer also has the potential to influence the nature of training and music. For example, across cultures, music and teaching occupy different places in social life and in their relation to other activities. With a few exceptions (e.g., Kaviani et al. 2014; Swaminathan and Gopinath 2013; Yang et al. 2014), most investigations of transfer have focused on samples of Western individuals learning Western music, which raises the possibility that many findings are Western specific. Unlike most other cognitive training programs, music and music training are cultural products that are meaningful in different ways to different individuals (see Colzato and Hommel this volume).

Music lessons require time, effort, and money. Parents, educators, and policy makers are often motivated to invest in music lessons so that children develop their musical talents and also their nonmusical skills such as focus, attention, intelligence, literacy, and school performance. Economic pressures, as a result, could cause certain types of music programs to be privileged over others. For example, if school-based group lessons are not particularly effective at training nonmusical skills, they could lose financial backing, which has implications regarding who has access to music lessons and what kind of lessons. In sum, because we are dealing with a real-world form of training nested in cultural contexts, the line between the laboratory and real world cannot be neatly defined. It is therefore important that research on music training and transfer becomes an interdisciplinary examination of the cultural contexts of producers and consumers of such research.

Conclusion

Despite having received much research attention, studies of transfer effects of music lessons have predominantly involved correlational designs, which make it impossible to determine whether music lessons are the cause rather than consequence of improved cognitive performance. Moreover, the relatively small number of experimental and longitudinal studies that exist tends to report small, limited, or mixed effects. As a way forward, we propose that future research could examine the extent to which music lessons train general and specific cognitive abilities, the mechanisms by which such transfer occurs, the characteristics of the trainee and training program, and the larger social context in which such training is received.

Acknowledgment Supported by the Natural Sciences and Engineering Research Council of Canada.

References

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and non-musicians. *Psychology of Music, 31*(2), 123–138.

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology, 6*, 282. doi:10.3389/fpsyg.2015.00282.

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology, 4*, 222. doi:10.3389/fpsyg.2013.00222.

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. *Music Perception, 29*(2), 195–201.

Degé, F., & Schwarzer, G. (2011). The effect of a music program on phonological awareness in preschoolers. *Frontiers in Psychology, 2*, 124. doi:10.3389/fpsyg.2011.00124.

Flaugnacco, E., Lopez, L., Terribili, C., Montico, M., Zoia, S., & Schön, D. (2015). Music training increases phonological awareness and reading skills in developmental dyslexia: A randomized control trial. *PLoS One, 10*(9). doi:10.1371/journal.pone.0138715.

Gordon, R. L., Shivers, C. M., Wieland, E. A., Kotz, S. A., Yoder, P. J., & McAuley, J. D. (2015). Musical rhythm discrimination explains individual differences in grammar skills in children. *Developmental Science, 18*(4), 635–644.

Goswami, U. (2012). Language, music, and children's brains: A rhythmic timing perspective on language and music as cognitive systems. In P. Rebuschat, M. Rohrmeier, J. A. Hawkins, & I. Cross (Eds.), *Language and music as cognitive systems* (pp. 292–301). Oxford, UK: Oxford University Press.

Helmbold, N., Rammsayer, T., & Altenmüller, E. (2005). Differences in primary mental abilities between musicians and nonmusicians. *Journal of Individual Differences, 26*(2), 74–85.

Kaviani, H., Mirbaha, H., Pournaseh, M., & Sagan, O. (2014). Can music lessons increase the performance of preschool children in IQ tests? *Cognitive Processing, 15*(1), 77–84.

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews. Neuroscience, 11*(8), 599–605.

Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., & White-Schwoch, T. (2014). Music enrichment programs improve the neural encoding of speech in at-risk children. *Journal of Neuroscience, 34*(36), 11913–11918.

Mehr, S. A., Schachner, A., Katz, R. C., & Spelke, E. S. (2013). Two randomized trials provide no consistent evidence for nonmusical cognitive benefits of brief preschool music enrichment. *PLoS One, 8*(12). doi:10.1371/journal.pone.0082007.

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science, 22*(11), 1425–1433.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: More evidence for brain plasticity. *Cerebral Cortex, 19*(3), 712–723.

Mosing, M. A., Madison, G., Pedersen, N. L., & Ullén, F. (2015). Investigating cognitive transfer within the framework of music practice: Genetic pleiotropy rather than causality. *Developmental Science, 19*, 504–512. doi:10.1111/desc.12306.

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing, 30*(6), 653–661.

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Frontiers in Psychology, 2*, 142. doi:10.3389/fpsyg.2011.00142.

Portowitz, A., Lichtenstein, O., Egorova, L., & Brand, E. (2009). Underlying mechanisms linking music education and cognitive modifiability. *Research Studies in Music Education, 31*(2), 107–128.

Roden, I., Grube, D., Bongard, S., & Kreutz, G. (2014). Does music training enhance working memory performance? Findings from a quasi-experimental longitudinal study. *Psychology of Music, 42*(2), 284–298.

Ruggles, D. R., Freyman, R. L., & Oxenham, A. J. (2014). Influence of musical training on understanding voiced and whispered speech in noise. *PLoS One, 9*(1). doi:10.1371/journal.pone.0086980.

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science, 15*(8), 511–514.

Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology, 102*(3), 283–302.

Schellenberg, E. G. (2015). Music training and speech perception: A gene–environment interaction. *Annals of the New York Academy of Sciences, 1337*(1), 170–177.

Schellenberg, E. G., & Moreno, S. (2010). Music lessons, pitch processing and g. *Psychology of Music, 38*(2), 209–221.

Schellenberg, E. G., & Peretz, I. (2008). Music, language and cognition: Unresolved issues. *Trends in Cognitive Sciences, 12*(2), 45–46.

Schellenberg, E. G., & Weiss, M. W. (2013). Music and cognitive abilities. In D. Deutsch (Ed.), *The psychology of music* (3rd ed., pp. 499–550). Amsterdam: Elsevier.

Slater, J., Skoe, E., Strait, D. L., O'Connell, S., Thompson, E., & Kraus, N. (2015). Music training improves speech-in-noise perception: Longitudinal evidence from a community-based music program. *Behavioural Brain Research, 291*, 244–252.

Strait, D. L., O'Connell, S., Parbery-Clark, A., & Kraus, N. (2014). Musicians' enhanced neural differentiation of speech sounds arises early in life: Developmental evidence from ages 3 to 30. *Cerebral Cortex, 24*(9), 2512–2521.

Swaminathan, S., & Gopinath, J. K. (2013). Music training and second-language English comprehension and vocabulary skills in Indian children. *Psychological Studies, 58*(2), 164–170.

Swaminathan, S., & Schellenberg, E. G. (2014). Arts education, academic achievement, and cognitive ability. In P. P. L. Tinio & J. K. Smith (Eds.), *The Cambridge handbook of the psychology of aesthetics and the arts* (pp. 364–384). Cambridge, UK: Cambridge University Press.

Tallal, P., & Gaab, N. (2006). Dynamic auditory processing, musical experience and language development. *Trends in Neurosciences, 29*(7), 382–390.

Thomson, J. M., Leong, V., & Goswami, U. (2013). Auditory processing interventions and developmental dyslexia: A comparison of phonemic and rhythmic approaches. *Reading and Writing, 26*(2), 139–161.

Yang, H., Ma, W., Gong, D., Hu, J., & Yao, D. (2014). A longitudinal study on children's music training experience and academic development. *Scientific Reports, 4*, 5854. doi:10.1038/srep05854.

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLoS One, 9*(6). doi:10.1371/journal.pone.0099868.

Physical Training

Kristell Pothier and Louis Bherer

Introduction

For many years, studies have suggested that lifestyle factors have a significant impact on how well people age (Kramer et al. 2004). Among numerous lifestyle factors, physical activity and exercise training have gained popularity as ecological approaches to develop and maintain cognitive health, and this could partly be due to its protective effects against the deleterious impacts of age on health and cognition. Studies supporting the benefits of physical activity and exercise on cognition are numerous, and methodologies vary greatly with regard to the type of activity and fitness assessment. *Physical activity* is defined as any bodily movement produced by skeletal muscles that results in energy expenditure. *Exercise* is a subtype of physical activity that is planned, structured, repetitive, and purposive (Caspersen et al. 1985). Physical activity assessment varies from direct observation and self-report questionnaires to pedometers, hip accelerometers, or ActiGraph systems. Physical activity assessment does not provide a direct measure of physical fitness, which should be assessed using a submaximal walking test (e.g., the Rockport one mile test; Kline et al. 1987) or a graded physical exercise test (on a treadmill or a cycle ergometer) to estimate or to provide a direct measure of VO_2 max, the ability of the body to transport and use oxygen during intense effort (Betik and Hepple 2008), which is considered as the gold standard for a cardiorespiratory fitness index.

Despite methodological differences among studies, systematic reviews and meta-analyses of longitudinal studies support the association between physical activity and cognitive function. In children, regular participation in physical activity was shown to be associated with enhanced brain function and cognition and positively related to academic performance (Singh et al. 2012). In older adults, regular

---

K. Pothier • L. Bherer (✉)
PERFORM Centre and Psychology Department, Concordia University,
Montreal, QC, Canada
e-mail: louis.bherer@concordia.ca

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_14

practice of physical activity is associated with a reduced risk of cognitive decline and dementia by 20 % (Weuve et al. 2004) to 35 % (Sofi et al. 2011). In fact, the risk of cognitive decline seems to be inversely proportional to the amount of physical activity practiced throughout life (Paillard 2015). However, it still remains unclear whether all types of physical activity impact cognition to the same extent or carry the same promise in terms of protection against cognitive decline. Moreover, the impact of exercise on biomarkers of cognitive decline remains understudied (Jensen et al. 2015).

This chapter reviews the literature assessing the impact of physical activity/exercise training as an effective way to maximize cognitive development in children, help maintain cognitive vitality across the life span, and alleviate the burden of aging on neurocognitive functions. It does not claim to be an exhaustive review. Rather, it aims to provide the reader with an overview of the recent advancement in scientific knowledge, mainly based on interventional studies assessing whether and how physical activity and exercise positively affect cognition. More specifically, we opted to focus on what type of specific physical activity or exercise can maximize cognitive development and attenuate the age-related cognitive decline. Although more studies are required to find definitive answers to these important questions, recent interventional studies including various exercises and the use of neuroimaging techniques have opened new research avenues. The following sections report evidence of cognitive improvement in interventional studies using aerobic training, strength or resistance training, gross motor and coordination training, and soft exercise such as yoga, dance, and tai chi.

Aerobic Training

Aerobic training usually involves exercises, such as jogging, swimming, or brisk walking that stimulate and strengthen the heart and lungs, with the goal of improving the body's utilization of oxygen. In a noteworthy study by Kramer et al. (1999), older adults who completed a 6-month walking program showed a greater significant improvement in tasks that tapped into attentional control or executive functions, compared to other cognitive functions and to a control group (of non-aerobic stretching exercise). This observation was further supported by a meta-analysis from Colcombe and Kramer (2003) of interventional studies (see also Bherer et al. 2013). In younger individuals (i.e., children and young adults), studies that employed vigorous aerobic-based exercise interventions also reported gains in executive functioning (Voss et al. 2011).

The biological mechanisms by which cognition is enhanced through aerobic exercise remain to be fully elucidated, but it has been suggested that aerobic exercise induces angiogenesis, neurogenesis, and synaptogenesis. Supports for this are exercise-associated changes in molecular growth factors such as brain-derived neurotrophic factor (BDNF), which plays a crucial role in neuroplasticity and neuroprotection, and increased production of insulin-like growth factor 1 (IGF-1)

(Jensen et al. 2015). In some studies, these observations paralleled change in brain structures and functions. For instance, in Voss et al. (2010, 2013), 12 months of an aerobic exercise intervention induced improvement in functional connectivity, which was associated with enhanced executive functions, serum level BDNF, and other growth factors.

Strength or Resistance Training

Strength or resistance training requires the body's musculature to move against an opposing force, usually using some type of training equipment. Recent studies also suggest that strength or resistance training can have beneficial effects on cognition, especially with older adults. Tsai et al. (2015) showed that a 12-month high-intensity resistance exercise intervention could effectively delay the decline in executive functions in healthy elderly males. In contrast, a meta-analysis by Kelly et al. (2014) only partially supported the benefits of resistance training on older adults' cognitive functions, with resistance training groups performing better than stretching/toning controls on only one out of three memory measures and four out of 18 executive function tests. Better comparability in behavioural measures of executive functions across studies could help explain discrepant results among studies.

Other studies offer more convincing support for the benefit of strength training exercise on brain plasticity. In a neuroimaging study, Liu-Ambrose et al. (2012) showed improved executive scores after a 6-month resistance program in conjunction with increased hemodynamic activity in brain regions associated with response inhibition, suggesting functional plasticity. This plasticity could potentially lie on a molecular pathway. In fact, Cassilhas et al. (2007) showed that both moderate- and high-intensity resistance trainings are associated with increased levels of IGF-1. Similarly, Tsai et al. (2015) showed an increase in serum IGF-1 levels after a long-term high-intensity resistance exercise program, which correlated with changes in reaction times and P3b amplitudes in an oddball task.

Gross Motor/Coordination Training

It has recently been observed that gross motor training involving coordination, balance, and agility activities can also lead to improvements in older adults' cognitive functions independently of aerobic fitness or resistance training. Voelcker-Rehage et al. (2011) reported improved executive control and perceptual speed after a 12-month coordination training program in older adults (aged 62–79 years). Forte et al. (2013) also reported improved executive control in adults aged 65–75 years after a 3-month multicomponent training program (including balance and agility). A more recent study (Berryman et al. 2014) compared aerobic training combined with strength training to gross motor activities training and observed equivalent improvement in an inhibition task across all training programs, highlighting again the beneficial impact of a gross motor training on cognition. Even though there is evidence that cognition and certain motor skills are linked in young individuals (see van der Fels et al. 2015 for a review in children aged 4–16 years old), there is still a lack of exercise intervention studies in these specific populations.

Little is known regarding biomarkers of gross motor/coordination training effects. Interestingly, Voelcker-Rehage et al. (2011) reported results suggesting that the neurocognitive mechanisms that underlie cognitive changes induced by exercise training could differ depending on training intervention, with cardiovascular training being associated with an increased activation of the sensorimotor network, while coordination training being linked to an increased activation in the visual–spatial network. Future studies are required to further understand how gross motor and coordination training impact specific cognitive functions.

Emerging Training Programs: Yoga, Dance, and Tai Chi

There is a growing interest for more ecological-like interventions, based on popular soft gymnastics such as yoga, dance, tai chi, etc. (see Verhaegen this volume, for a review on the effects of meditation on cognitive functions). This section mainly reports some interventional studies. Further research will be needed to complete this emerging literature, particularly with regard to potential biomarkers.

Yoga is a widely practiced form of meditation and relaxation with origins in ancient Indian philosophy. It includes postures combined with breathing techniques and is now classified as a form of complementary and alternative medicine by the National Institutes of Health. In a recent literature review of studies with older adults, Patel et al. (2012) found no improvement in global cognition nor in alertness and attention after yoga training compared to control conditions. However, using a rigorous study design, Gothe et al. (2013) examined the effects of an 8-week Hatha yoga intervention on executive functions in 118 healthy older adults (55–79 years old). Results showed improved performance in measures of working memory, mental set shifting, and flexibility in the yoga group, but not in the stretching–strengthening control group. Practicing yoga could also be beneficial at younger age. In fact, a recent study including 200 schoolchildren found that a 3-month yoga intervention was particularly beneficial for the cognitive domains of attention and visuospatial abilities (Chaya et al. 2012). Regarding biomarkers, Pal et al. (2014) recently found a significant improvement in plasma BDNF level for males aged 20–50 who experimented yoga practice for 3 months, 1 h per week. The impact of yoga on stress level (i.e., cortisol), psychological well-being (serotonin and dopamine levels), and its potentially beneficial effects on reducing the risk for cerebrovascular disease (lipid profiles and lower oxidative stress) seems to be promising avenue of investigation.

Dancing has recently gained interest in the scientific community. Compared to other activities such as aerobic or resistance training, dancing offers a combination of physical, cognitive, and social activities potentially useful for attenuating age-related decline. A recent review of the literature (McNeely et al. 2015) showed a strong effect of dance on cognition in older adults. The review included ten studies in which older adults underwent multi-session dance interventions (e.g., salsa, ballroom, contemporary, etc.) between 8 weeks and 18 months, with at least one session a week. Besides positive effects in quality of life (e.g., body pain, physical functioning, or life satisfaction), cognition was improved after a dance intervention, with more specific effects on task switching and response speed. However, none of the dance interventions seemed to affect attention, visuospatial memory, or fluid intelligence. Here again, future studies will help clarify and understand the impact of dance on specific cognitive functions in seniors.

Tai Chi, meaning "supreme ultimate boxing," is originally a martial art from China combining the exercise of rhythmic movement and self-defense practice with the use of yogic breathing techniques. It involves moving from a standing position through a series of postures. Like yoga or dance, tai chi could be described as being a combined intervention, with physical, cognitive, and social characteristics occurring simultaneously. A recent study in children showed that tai chi could be a useful tool to incorporate in educational programs to improve well-being, sleep, or self-awareness (Wall 2005). In older adults, Chang et al. (2010) found mixed results with regard to cognitive performance. However, a recent meta-analysis highlighted the impact of tai chi on attention, processing speed, and working memory in older adults (Kelly et al. 2014). Studies using neuroimaging techniques are still scarce, but Wei et al. (2013) recently found in middle-aged adults that compared with control participants who never practiced tai chi, those who have practiced it for many years showed thicker cortex in the precentral gyrus, insula sulcus, and middle frontal sulcus in the right hemisphere and superior temporal gyrus, medial occipitotemporal sulcus, and lingual sulcus in the left hemisphere. Although this was a cross-sectional study, it provides partial support to the notion that long-term tai chi practice could induce regional structural changes. Well-designed intervention studies are needed to further support these observations.

What Would Be the Best Physical Activity/Exercise?

At this time, we still have insufficient evidence to determine whether specific modalities of exercise have a differential effect on cognitive performance. Over the last decade or so, numerous studies and meta-analyses have reported supporting evidence that aerobic exercise can lead to cognitive improvement. More recently though, strength and resistance training, gross motor training, and other approaches have gained more interest, specifically with older adult populations. Consequently, it is hard to provide definitive conclusions regarding the volume and intensity of exercise, as well as the duration of an intervention that would best lead to cognitive improvement. The literature in younger individuals would benefit from having more training intervention studies with objective measures of physical activity in order to gain insight into the dose–response relationship between physical activity and academic performance. Equally important are the individual differences in fitness level, sedentary lifestyle, and gender differences, which also increasingly seem to become important moderators of fitness intervention effects (see Katz et al. this volume, for a review on individual differences in cognitive training research).

In regard to training duration, a minimum of a 12-week intervention seems to be ideal to improve physical components, depending on which specific components are part of the desired outcome (e.g., from 12 weeks for better balance to 50 weeks for improving muscle morphology, with a minimum of 16 weeks to improve VO_2 max, while some studies including ours show significant improvement after 12 weeks in sedentary seniors, Predovan et al. 2012). Many of the studies published so far suggest a training frequency of three 1-h sessions per week to obtain significant physical adaptation or changes. For positive effects on cognition, studies show more equivocal results that could be linked to variability in study designs, characteristics of the population, and training modalities. In their recent review of observational studies in healthy older adults and patients with diverse pathologies (prospective cohort studies, case–control studies, and longitudinal studies), Carvalho et al. (2014) observed that studies' duration varies from 6 months to several years across studies. Future studies should investigate if this could have an impact on cognitive benefits overall and if it could lead to differential gains on various cognitive functions.

As for the content of the ideal training intervention, great results have been observed with combined aerobic and strength training regiments, although brisk walking also showed large benefits on cognition and can potentially induce brain plasticity as suggested by results from studies using brain imaging techniques (Erickson et al. 2011). There is also a trend supporting the use of combining physical exercise with another activity (such as cognitive training) with hope that it could boost cognition further than exercise alone. However, the effects of these so-called multi-domain interventions on cognition have not clearly been demonstrated yet (Schneider and Yvon 2013). Moreover, in some multi-domain intervention studies, the training protocol consisted of giving participants twice as many training sessions than the physical or the cognitive training group alone. As a result, it could sometimes be hard to dissociate the effect of combining intervention from the mere impact of increasing the volume of training. In order to maintain the benefits longer, training might include various components at the same time, like in yoga, dance, or tai chi combining simultaneously physical, cognitive, and social components. An interesting and newly created program (called "life kinetic," Lutz 2012) shows promising results (see Demirakca et al. 2016 for an fMRI study in middle-aged adults). It combines coordinative, cognitive, and visual tasks in a way that the physical exercise is performed while participants are cognitively challenged at the same time (mainly on working memory). One of the advantages of this simultaneous training probably lies on the involvement of a more ecological dual-task design in which participants have to constantly switch attention between cognitive and physical activities.

Conclusion

This chapter is a brief overview of a substantial literature supporting the notion that physical activity and exercise training can positively affect cognitive development across the human life span. In many studies, aerobic training seems to largely impact the executive functioning of healthy older adults, and these effects could be, at least in part, induced by improvement in oxygen consumption (e.g., higher VO_2 max measures). Moreover, the neuroprotective effect of exercise could be supported by a cascade of molecular mechanisms that involve regulation of specific biomarkers (BDNF, IGF-1) that are known to play a role in brain integrity or repair and plasticity. Some of these biomarkers might also be involved in the effects of resistance intervention on executive control performance. Emerging interventions based on gross motor exercise, yoga, dance, or tai chi also demonstrated positive effects on cognition. Based on the results of most of these studies, it seems that simultaneously combining physical and cognitive exercise represents a new interesting path that deserves further investigation. Nevertheless, some important methodological questions remain to be elucidated. Among other issues, future studies should help develop more ecological interventions based on individuals' interests and further investigate short-term benefits and long-term gains of the intervention programs. Future studies should also help uncover potential important moderators for the effects of fitness interventions (e.g., sedentary lifestyle or gender differences) on cognition and elucidate biological mechanisms that sustain the positive impacts that exercise induces on brain structure and functions throughout life.

References

Berryman, N., Bherer, L., Nadeau, S., Lauziere, S., Lehr, L., Bobeuf, F., Lussier, M., Kergoat, M. J., Vu, T. T., & Bosquet, L. (2014). Multiple roads lead to Rome: Combined high-intensity aerobic and strength training vs. gross motor activities leads to equivalent improvement in executive functions in a cohort of healthy older adults. *Age (Dordrecht, Netherlands), 36*, 9710.

Betik, A. C., & Hepple, R. T. (2008). Determinants of VO2max decline with aging: An integrated perspective. *Applied Physiology, Nutrition, and Metabolism, 33*(1), 130–140.

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research, 2013*, 657508. doi:10.1155/2013/657508.

Carvalho, A., Rea, I. M., Parimon, T., & Cusack, B. J. (2014). Physical activity and cognitive function in individuals over 60 years of age: A systematic review. *Clinical Interventions in Aging, 9*, 661–682.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126–131.

Cassilhas, R. C., Viana, V. A., Grassmann, V., et al. (2007). The impact of resistance exercise on the cognitive function of the elderly. *Medicine and Science in Sports and Exercise, 39*(8), 1401–1407.

Chang, Y. K., Nien, Y. H., Tasi, C. L., & Etnier, J. L. (2010). Physical activity and cognition in older adults: The potential of Tai Chi Chuan. *Journal of Aging and Physical Activity, 18*, 451–472.

Chaya, M. S., Nagendra, H., Selvam, S., Kurpad, A., & Srinivasan, K. (2012). Effect of yoga on cognitive abilities in schoolchildren from a socioeconomically disadvantaged background: A randomized controlled study. *Journal of Alternative and Complementary Medicine, 18*(12), 1161–1167. doi:10.1089/acm.2011.0579.

Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*, 125–130.

Demirakca T., Cardinale V., Dehn S., Ruf M., & Ende G. (2016). The exercising brain: Changes in functional connectivity induced by an integrated multimodal cognitive and whole-body coordination training. *Neural Plasticity,* Article ID 8240894, 11 p. doi:10.1155/2016/8240894.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., White, S. M., et al. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences of the United States of America, 108*, 3017–3022.

Forte, R., Boreham, C. A., Leite, J. C., De Vito, G., Brennan, L., Gibney, E. R., & Pesce, C. (2013). Enhancing cognitive functioning in the elderly: Multicomponent vs resistance training. *Clinical Interventions in Aging, 8*, 19–27. doi:10.2147/CIA.S36514.

Gothe, N., Pontifex, M. B., Hillman, C. H., & McAuley, E. (2013). The acute effects of yoga on executive function. *Journal of Physical Activity and Health, 10*, 488–495.

Jensen, C. S., Hasselbalch, S. G., Waldemar, G., & Simonsen, A. H. (2015). Biochemical markers of physical exercise on mild cognitive impairment and dementia: Systematic review and perspectives. *Frontiers in Neurology, 6*, 187. doi:10.3389/fneur.2015.00187.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of exercise on the cognitive functioning of healthy older adults: A systematic review and meta-analysis. *Ageing Research Reviews, 16*, 12–31.

Kline, G. M., Porcari, J. P., Hintermeister, R., Freedson, P. S., Ward, A., McCarron, R. F., et al. (1987). Estimation of VO2max from a one-mile track walk, gender, age, and body weight. *Medicine & Science in Sports & Exercise, 19*(3), 253–259.

Kramer, A. F., Bherer, L., Colcombe, S. J., Dong, W., & Greenough, W. T. (2004). Environmental influences on cognitive and brain plasticity during aging. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59*, 940–957.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., & Colcombe, A. (1999). Ageing, fitness and neurocognitive function. *Nature, 400*(6743), 418–419.

Liu-Ambrose, T., Nagamatsu, L. S., Voss, M. W., Khan, K. M., & Handy, T. C. (2012). Resistance training and functional plasticity of the aging brain: A 12-month randomized controlled trial. *Neurobiology of Aging, 33*(8), 1690–1698.

Lutz, H. (2012). *Life Kinetik®—Gehirntraining durch Bewegung* (3rd ed.). München: Bayrischer Landwitschaftsverlag.

McNeely, M. E., Duncan, R. P., & Earhart, G. M. (2015). Impacts of dance on non-motor symptoms, participation, and quality of life in Parkinson disease and healthy older adults. *Maturitas, 82*, 336–341.

Paillard, T. (2015). Preventive effects of regular physical exercise against cognitive decline and the risk of dementia with age advancement. *British Journal of Sports Medicine, 4*, 1–6.

Pal, R., Singh, S. N., Chatterjee, A., & Saha, M. (2014). Age-related changes in cardiovascular system, autonomic functions, and levels of BDNF of healthy active males: Role of yogic practice. *Age (Dordrecht, Netherlands), 36*, 9683.

Patel, N. K., Newstead, A. H., & Ferrer, R. L. (2012). The effects of yoga on physical functioning and health related quality of life in older adults: A systematic review and meta-analysis. *Journal of Alternative and Complementary Medicine, 18*(10), 902–917.

Predovan, D., Fraser, S. A., Renaud, M., & Bherer, L. (2012). The effect of three months of aerobic training on stroop performance in older adults. *Journal of Aging Research, 269815*.

Schneider, N., & Yvon, C. (2013). A review of multidomain interventions to support healthy cognitive ageing. *The Journal of Nutrition, Health & Aging, 17*(3), 252–257.

Singh, A., Uijtdewilligen, L., Twisk, J. W. R., van Mechelen, W., & Chinapaw, M. J. M. (2012). Physical activity and performance at school. A systematic review of the literature including a methodological quality assessment. *Archives of Pediatrics and Adolescent Medicine, 166*(1), 49–55. doi:10.1001/archpediatrics.2011.716.

Sofi, F., Valecchi, D., Bacci, D., et al. (2011). Physical activity and risk of cognitive decline: A meta-analysis of prospective studies. *Journal of Internal Medicine, 169*, 107–117.

Tsai, C. L., Wang, C. H., Pan, C. Y., & Chen, F. C. (2015). The effects of long-term resistance exercise on the relationship between neurocognitive performance and GH, IGF-1, and homocysteine levels in the elderly Front. *Behavioral Neuroscience, 9*, 23.

van der Fels, I. M., Te Wierike, S. C., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport, 18*(6), 697–703.

Voelcker-Rehage, C., Godde, B., & Staudinger, U. M. (2011). Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. *Frontiers in Human Neuroscience, 5*, 26. doi:10.3389/fnhum.2011.00026.

Voss, M. W., Erickson, K. I., Prakash, R. S., et al. (2013). Neurobiological markers of exercise-related brain plasticity in older adults. *Brain, Behavior, and Immunity, 28*, 90–99.

Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the lifespan. *Journal of Applied Physiology, 111*, 1505–1513.

Voss, M. W., Prakash, R. S., Erickson, K. I., et al. (2010). Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. *Frontiers in Aging Neuroscience, 2*, 1–17.

Wall, R. B. (2005). Tai Chi and mindfulness-based stress reduction in a Boston Middle School. *Journal of Pediatric Health Care, 19*, 23–237.

Wei, G. X., Xu, T., Fan, F. M., Dong, H. M., Jiang, L. L., Li, H. J., Yang, Z., Luo, J., & Zuo, X. N. (2013). Can taichi reshape the brain? A brain morphometry study. *PLoS One, 8*(4), e61038.

Weuve, J., Kang, J. H., Manson, J. E., Breteler, M. M., Ware, J. H., & Grodstein, F. (2004). Physical activity, including walking, and cognitive function in older women. *JAMA, 292*, 1454–1461.

Part V
Cognitive Training in Applied Contexts

Individual Differences and Motivational Effects

Benjamin Katz, Masha R. Jones, Priti Shah, Martin Buschkuehl, and Susanne M. Jaeggi

Introduction

Reproducibility is an essential feature of high-quality psychological research, and the subfield of cognitive training has produced no shortage of replications and follow-up studies. For example, one intervention developed by two of the authors of this chapter, n-back training, has been used in no less than fourteen studies from other research groups that also examined training in the context of transfer to fluid intelligence (Au et al. 2014). The outcome of these studies, however, is inconsistent: While some studies find improvements in untrained tasks following the intervention, others do not. Although these subsequent studies may not adhere to the level of fidelity with the original research that was attempted in the recent Reproducibility Project (Open Science Collaboration 2015), similar or identical training paradigms and transfer tasks were used. How does one make sense of not only a single failed or successful replication but an entire corpus of divergent results?

One potential answer to this conundrum is the use of meta-analytic techniques, as these allow researchers to determine not only whether an intervention has a meaningful effect over a large body of studies but also to reveal potential moderators—such as demographic makeup, pre-existing individual differences, or training dosage—

B. Katz (✉) • P. Shah
Department of Psychology, University of Michigan, Ann Arbor, MI, USA
e-mail: benkatz@umich.edu; priti@umich.edu

M.R. Jones • S.M. Jaeggi
School of Education, University of California, Irvine, CA, USA
e-mail: m.jones@uci.edu; smjaeggi@uci.edu

M. Buschkuehl
MIND Research Institute, Irvine, CA, USA
e-mail: mbuschkuehl@mindresearch.net

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_15

that may influence the outcome of the intervention. However, even the handful of extant meta-analyses (Au et al. 2014; Karbach and Verhaeghen 2014; Melby-Lervåg and Hulme 2013; Schwaighofer et al. 2015) arrive at different conclusions about the efficacy of cognitive training. A brief interrogation of these quantitative reviews makes this outcome unsurprising, considering that each meta-analysis relied on different selection criteria for including studies and somewhat different methodologies to calculate effect sizes. Some debate has occurred regarding the specific procedures used in each of these meta-analyses; however, it is reasonable to suggest that, as long as sensible alternatives exist in methodology that deliver divergent results, meta-analyses of existing studies alone may be insufficient for reaching consensus about the efficacy of cognitive training.

In this chapter we suggest an alternate solution to the issues facing cognitive training research. There is compelling evidence that cognitive training is not equally effective for all participants across all studies. Rather, it is likely that certain individual difference factors such as age, baseline performance, socioeconomic status, personality, experience with games, and motivation, among many others, may impact the outcome of the intervention for any individual participant. These differences have significant implications not only for our ability to improve our theoretical understanding of cognitive training but also for the real-world efficacy of any individual intervention. However, many extant cognitive training studies do not examine these factors. Furthermore, most use sample sizes that are too small to adequately account for them individually, let alone the extent they may interact with each other. Conducting larger, better-powered studies that allow scientists to understand the effects of these differences may help to explain the inconsistency across studies thus far. This chapter focuses on the evidence that certain individual difference factors may influence the outcome of cognitive training, with the hope that researchers may examine them more closely in future studies. Additionally, given the importance of transferability to untrained tasks in cognitive training research, the present chapter focuses primarily on the contribution of these individual difference factors to improvements on transfer tasks, although these factors are also discussed with respect to training gains when relevant.

Individual Difference Factors that May Influence Cognitive Training Outcomes

A full discussion of all the individual difference factors that *might* influence the outcome of cognitive training would require a book by itself. For a comprehensive review of how individual difference factors impact cognition more generally, the *Handbook of Individual Differences in Cognition* (Gruszka et al. 2012) provides a detailed discussion. For the purposes of this introduction to the topic, however, we focus on individual difference factors that have been examined in previous working memory and executive function training research. This list, perhaps unsurprisingly given the previous paragraphs, is fairly short—only a handful of the many cognitive training studies published thus far have explicitly examined individual difference factors. At present, these studies consider age, baseline performance, personality factors, and motivation. Readers well versed in the study of individual differences may notice other factors that may be meaningful predictors in other contexts—such as gender or cultural factors[1]—missing from this chapter. While these certainly merit further study, we exclude them here simply because extant research does not yet suggest that they make a significant contribution to the outcome of a cognitive training paradigm.

Baseline Performance

The potential contribution of baseline performance (either on the training task itself or on the set of cognitive tests used at pretest) to improvements on untrained assessments merits primacy in a discussion of individual differences. While many individual difference factors have not been specifically studied in the context of cognitive training, most of these *have* been examined in the context of baseline performance on a variety of cognitive abilities, such as working memory or executive function. If baseline performance impacts the outcome of a training intervention, it is reasonable to suggest that the other individual difference factors that influence baseline performance merit further investigation; the influence of baseline performance in a domain on its trainability has long been a focus of cognitive training research (Verhaeghen et al. 1992; 1992; Willis 1989; see also Snow 1991). Baseline performance on working memory tasks may influence the outcome of cognitive training in one of two directions. One possibility is that those who perform worse prior to the intervention have more room to improve following training and thus may experience greater gains. Alternatively, those with higher baseline performance may be better able to benefit from completing a cognitive training regimen—they may perform better at the training task over the course of the intervention and thus also experience greater improvements; these participants may also be more likely to complete the entire intervention and not drop out of a study (Jaeggi et al. 2014). One factor to keep in mind is that the source of individual differences in baseline performance may differ across studies: in some studies lower baseline individuals may have less experience, be younger or older, and so forth. Thus, it is not surprising that baseline performance may have different effects across studies. It is also possible that different training paradigms may result in different patterns of performance across high- and low-baseline participants. For example, process-based training often results in higher gains for individuals with lower baseline performance, while strategy-based training programs often result in greater gains for high-baseline

---

[1] While Au et al. (2014) did find differences between cognitive training studies conducted in the United States compared to other countries, it remains unclear whether those differences are related to cultural or other factors (e.g., motivation).

individuals (Karbach and Unger 2014). Thus, a sensible approach to resolving these issues is to focus on the underlying individual differences that may influence baseline performance as well as training paradigm characteristics.

Of the few studies examining baseline performance and cognitive training, a number support the former possibility—that is, that those who start with lower levels of performance experience greater gains. In two studies by Zinke et al. (2012, 2014) individuals who performed worse at baseline, across multiple training paradigms of both working memory and executive control, experienced larger gains on the training task. Although Zinke et al. did not directly examine how baseline performance on untrained WM or fluid intelligence measures impacts transfer gains, they did find that, like Jaeggi et al. (2011), Schmiedek et al. (2010), and Chein and Morrison (2010), the amount of improvement on the training task does contribute to the amount of transfer gains on certain executive control and verbal WM tasks. These studies suggest that individuals who begin with lower baseline performance on the trained tasks may have stood to improve more at both the training and related transfer tasks. One possibility, as Zinke and colleagues discuss, is that individuals with higher baseline performance may be closer to ceiling performance at the task. If improvement in the task is a necessary precursor to transfer gains, it is also possible that modifying the task to permit high performers to continue improving beyond present ceiling levels might also permit them to experience greater transfer gain.

Few studies have specifically looked at how pretest performance on the transfer tasks may influence transfer gain, although consistent with the previously mentioned small studies, one recent, large-scale study found that individuals who performed worse at pretest on the set of transfer tasks also showed greater improvements on these tasks following training than those with higher pretest scores (Hardy et al. 2015). This finding is also consistent with research conducted on the ACTIVE training project with older adults (Willis and Caskie 2013) that found that lower performance on certain baseline measures was correlated with greater improvement after a period of cognitive training. While these studies provide some evidence that lower-performing individuals may stand to benefit more from the training than those who are closer to ceiling, the relationship between baseline ability and transfer may be fairly complex and might also be influenced by methodological differences, such as the design of the intervention or the adaptivity algorithms used to increase or decrease the difficulty of training. And finally, some of the outcome measures might not be sensitive enough to detect changes at the upper end of the scale, which could also contribute to the relatively smaller improvements observed in high-ability samples.

Age

A substantial body of research provides evidence for the effects of age on cognitive plasticity across the lifespan (Guye et al. of this volume); it should be unsurprising that age has often been linked to differences in transfer improvements following cognitive training. Several studies have found that improvements on untrained tasks are smaller for older adults than younger adults (Zinke et al. 2014; Brehmer et al. 2012; Schmiedek et al. 2010) and even smaller for old-old adults, when compared to young-old individuals (Borella et al. 2014). However, meta-analytic work has revealed inconsistent findings on this issue: While one recent meta-analysis found no difference between younger and older adults in transfer improvements (Karbach and Verhaeghen 2014), another found that younger adults improved more on these tasks than older adults (Wass et al. 2012). Given that these meta-analyses include different sets of studies based on differing parameters (e.g., Wass et al. include a larger range of ages than Karbach and Verhaeghen), it is difficult to compare them to each other.

Given the extent to which age impacts baseline performance on a wide variety of cognitive tasks (Salthouse 1996), there is a reasonable impetus for examining the effects of age in cognitive training research. Furthermore, if training mitigates the effects of age-related cognitive decline, older adult populations may benefit the most from cognitive training (Richmond et al. 2011). Perhaps most problematic, from the perspective of critiquing extant research, is that age effects have generally been examined only in the context of older versus younger adults, or in children, with the exception of Borella et al. (2014) mentioned above. Little is known about how age may impact transfer in individuals who are older than college age but younger than retirement, and until a truly comprehensive study is made that includes the entire lifespan—from children to young adults to middle age to older adults—a significant gap remains in our understanding of age as an individual difference factor relevant to cognitive training research.

Personality

A new line of research on cognitive training has begun to examine how individual differences in personality and temperament may moderate training gains and transfer effects. The findings from these studies seem to suggest that emotional stability is an important factor moderating the efficacy of cognitive training.

Conscientiousness is one moderating factor that has been investigated. A highly conscientious person tends to be persistent, hardworking, self-disciplined, and competitive. Not surprisingly, individuals with high levels of conscientiousness tend to have high training scores and improvements in near transfer tasks (Studer-Luethi et al. 2012). A surprising finding, however, is that participants with high levels of conscientiousness tend to have lower levels of improvement in far transfer measures. This finding suggests that conscientious individuals are able to develop successful, though nontransferable, task-specific skills (Studer-Luethi et al. 2012). However, given that this was a fairly small study sample, the range of personality factors was somewhat restricted. Thus, the results are considered preliminary, and further investigation is needed.

Related to conscientiousness is a factor called effortful control, which describes individual differences in emotional stability and the ability to self-regulate one's behavior depending on current and future goals. For example, children with high levels of effortful control are better able to overcome negative effect in order to achieve a goal. Consistent with the findings from (Studer-Luethi et al. 2012; Studer-Luethi et al. 2015), found that high effortful control and low neuroticism, a characteristic describing anxious and emotionally unstable individuals, best predicted transfer effects and suggest that cognitive training is most effective when children are emotionally stable and able to sufficiently self-regulate their emotions (Studer-Luethi et al. 2015).

This hypothesis is in line with the finding by Urbánek and Marček (2015) that individuals who scored high on the rhapsodic Personality Styles and Disorders Inventory, indicating an extravagantly emotional personality type, as well as schizotypal individuals who are typically highly anxious in social situations, were less likely to perform well on transfer tasks after training (Urbánek and Marček 2015). Similarly, neuroticism has been associated with lower training scores and lower performance on transfer tasks (Studer-Luethi et al. 2012). These personality types likely have a negative influence on training outcomes due to processing capacity being limited by disadvantageous arousal levels, intrusive thoughts, and negative emotions (Studer-Luethi et al. 2015).

Based on this work, emotional stability appears to be an important personality factor to take into account for cognitive training. Future work should consider the underlying mechanisms behind personality differences as well as other personality differences, such as openness to experience, which has not only been correlated with cognitive ability (Schaie et al. 2004) but has also shown to be changed as a function of cognitive training (Jackson et al. 2012).

Motivation

Despite being an entire subfield of psychological research, few studies examine how a participant's motivation, either to complete the intervention or to improve their cognitive capacity, impacts training and transfer. A number of previous training studies inform participants that they may improve their intelligence or cognitive function during the study (Jaeggi et al. 2008; Klingberg et al. 2005), while other studies only mention practicing computerized tasks (Redick et al. 2013). One study, from the authors of this chapter, suggests that personal beliefs about the malleability of intelligence may contribute to the amount of transfer after a cognitive training intervention (Jaeggi et al. 2014). Individuals who believed that intelligence could be improved experienced larger transfer gains following training. Although the beliefs-by-intervention interaction was not significant in this instance, it does suggest that personal beliefs about whether one is able to improve cognition—itself a major factor in how motivated one might be to complete cognitive training—could have a substantial impact on the outcome of training. Additionally, the use of payment or other forms of extrinsic motivators as a means of incentive in training studies may also undermine the outcome of the intervention. The sole meta-analysis that examined compensation levels in the context of transfer gain points toward a negative impact of renumeration on transfer improvements (Au et al. 2014). However, findings from a recent study conducted in our laboratory specifically designed to measure the impact of renumeration suggests that payment may not necessarily have an undermining influence when participants also have intrinsic motivation to complete the training (Katz et al. submitted for publication).

One curious point related to motivation is the inclusion of “game-like” elements in cognitive training paradigms that are meant to motivate or engage participants. A number of cognitive training programs have been designed to mimic the motivational elements of video games (Jaeggi et al. 2011; Klingberg et al. 2005), while others do not include these game-like features, such as scoring, feedback, or animations. There is some evidence that game elements may influence performance on the tasks involved (Katz et al. 2014), although this one study from our laboratory suggests that adding game-like features may undermine training and transfer if they distract a participant from the core task. Interestingly, this difference has appeared most sharply in training targeted toward children versus training targeted toward adults, as if there is an expectation by researchers that game-like features are more motivating for younger individuals than older ones. Clearly, more work is needed to better understand the role of motivation in cognitive training as well as what researchers can do to best motivate their participants.

Conclusion

It may be somewhat disconcerting that extant research cannot yet pinpoint all individual differences that play a significant role in the outcome of cognitive training. We suggest that, at present, it is enough simply to illustrate that many of these factors *can* play a role in the outcome of training. Whether or not each individual difference factor is meaningful, one thing can be concluded for certain: We cannot know the extent to which they matter if we do not measure them. Furthermore, there is likely to be multicollinearity of variables when multiple individual difference measures are assessed, and it may be difficult to identify the primary factors. Some factors, like age, are often examined in cognitive training studies, while others, such as motivation, personality, socioeconomic status, and psychopathology, are generally not considered in cognitive training research. Given that most cognitive training studies only include a relatively small number of participants, this is a significant oversight—in an underpowered study, each of these factors could have an oversized effect. For example, given that Au and colleagues’ (2014) meta-analysis suggests an effect of one particular motivational factor—renumeration—on transfer, it is possible that the other meta-analyses discussed here, none of which examine motivation or renumeration, may have reached different conclusions were they to examine these factors. But it is important to keep in mind that even the most carefully conducted meta-analysis is only as strong as the sum of the studies it includes. Future cognitive training studies should include these factors as variables of interest, and furthermore, they must be adequately powered to fully examine them.

Finally, if some of these factors have a significant impact on transfer improvements, they may need to be incorporated into training paradigms themselves. If older adults experience smaller training gains than younger adults and the amount of training improvement predicted transfer, would it make sense to offer them the same training paradigm? A physical trainer does not offer the same training regimen to two individuals with different levels of baseline fitness nor does a clinical psychologist offer identical courses of therapy to individuals facing different mental health issues—or even the same mental health issues; for example, aptitude-treatment interaction methods have been used to take individual differences into account in psychotherapy interventions with considerable success (Snow 1991). There is no "one-size-fits-all" in human intervention research. And yet this is precisely what is often done in cognitive training studies: Individuals who may have vastly different motivations, baseline performance, and educational backgrounds find themselves facing identical training paradigms that, even if they are adaptive, do not take into account these individual differences. Better measurement and larger sample sizes may help us understand how these factors contribute to the outcome of training, but personalized training programs, which build these factors into the training paradigm itself, may ultimately help researchers create cognitive training regimens that are more effective—for all participants.

References

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2014). Improving fluid intelligence with training on working memory: A meta-analysis. *Psychonomic Bulletin & Review, 22*(2), 366–377. doi:10.3758/s13423-014-0699-x.

Borella, E., Carretti, B., Cantarella, A., Riboldi, F., Zavagnin, M., & De Beni, R. (2014). Benefits of training visuospatial working memory in young–old and old–old. *Developmental Psychology, 50*(3), 714–727. doi:10.1037/a0034293.

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: Training gains, transfer, and maintenance. *Frontiers in Human Neuroscience, 6*, 63. doi:10.3389/fnhum.2012.00063.

Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: Training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review, 17*(2), 193–199. doi:10.3758/PBR.17.2.193.

Gruszka, A., Matthews, G., & Szymura, B. (Eds.). (2012). *Handbook of individual differences in cognition: Attention, memory, and executive control* (pp. 295–320). New York: Springer. doi:10.1007/978-1-4419-1210-7.

Hardy, J. L., Nelson, R. A., Thomason, M. E., Sternberg, D. A., Katovich, K., Farzin, F., et al. (2015). Enhancing cognitive abilities with comprehensive training: A large, online, randomized, active-controlled trial. *PLoS One, 10*(9), 1–17. doi:10.1371/journal.pone.0134467.

Jackson, J. J., Hill, P. L., Payne, B. R., Roberts, B. W., & Stine-Morrow, E. A. (2012). Can an old dog learn (and want to experience) new tricks? Cognitive training increases openness to experience in older adults. *Psychology and Aging, 27*(2), 286–292. doi:10.1037/a0025918.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America, 105*(19), 6829–6833. doi:10.1073/pnas.0801268105.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short-and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences, 108*(25), 10081–10086. doi:10.1073/pnas.1103228108.

Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, J. (2014). The role of individual differences in cognitive training and transfer. *Memory & Cognition, 42*(3), 464–480. doi:10.3758/s13421-013-0364-z.

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390. doi:10.3389/fpsyg.2014.00390.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*(11), 2027–2037. doi:10.1177/0956797614548725.

Katz, B., Jaeggi, S., Buschkuehl, M., Shah, P., & Jonides, J. (submitted for publication). The effect of monetary compensation on cognitive training.

Katz, B., Jaeggi, S., Buschkuehl, M., Stegman, A., & Shah, P. (2014). Differential effect of motivational features on training improvements in school-based cognitive training. *Frontiers in Human Neuroscience, 8*, 242. doi:10.3389/fnhum.2014.00242.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., et al. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry, 44*(2), 177–186. doi:10.1097/00004583-200502000-00010.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270–291. doi:10.1037/a0028228.

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science, 349*(6251), 943–951. doi:10.1126/science.aac4716.

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., et al. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General, 142*(2), 359–379. doi:10.1037/a0029082.

Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging, 26*(4), 813–822. doi:10.1037/a0023631.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403–428. doi:10.1037/0033-295X.103.3.403.

Schaie, K. W., Willis, S. L., & Caskie, G. I. (2004). The Seattle longitudinal study: Relationship between personality and cognition. *Aging, Neuropsychology, and Cognition, 11*(2–3), 304–324. doi:10.1080/13825580490511134.

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience, 2*, 27. doi:10.3389/fnagi.2010.00027.

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist, 50*(2), 138–166. doi:10.1080/00461520.2015.1036274.

Snow, R. E. (1991). Aptitude-treatment interaction as a framework for research on individual differences in psychotherapy. *Journal of Consulting and Clinical Psychology, 59*(2), 205–216. doi:10.1037/0022-006X.59.2.205.

Studer-Luethi, B., Bauer, C., & Perrig, W. J. (2015). Working memory training in children: Effectiveness depends on temperament. *Memory & Cognition, 44*(2), 171–186. doi:10.3758/s13421-015-0548-9.

Studer-Luethi, B., Jaeggi, S. M., Buschkuehl, M., & Perrig, W. J. (2012). Influence of neuroticism and conscientiousness on working memory training outcome. *Personality and Individual Differences, 53*(1), 44–49. doi:10.1016/j.paid.2012.02.012.

Urbánek, T., & Marček, V. (2015). Investigating the effectiveness of working memory training in the context of Personality Systems Interaction theory. *Psychological Research, 1–12*. doi:10.1007/s00426-015-0687-4.

Willis, S. L. (1989). Improvement with cognitive training: Which old dogs learn what tricks? In Poon, L. W., Rubin, D. C., & Wilson, B. A. (Eds.), *Everyday cognition in adulthood and late life* (pp. 545–569). New York, NY: Cambridge University Press; xii, 708 pp. doi:10.1017/CBO9780511759390.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: a meta-analytic study. Psychology and aging, 7(2), 242. doi:10.1037/0882-7974.7.2.242.

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory–Is younger, better?. Developmental Review, 32(4), 360-387.doi:10.1016/j.dr.2012.07.001.

Willis, S. L., & Caskie, G. I. (2013). Reasoning training in the ACTIVE study: how much is needed and who benefits? *Journal of Aging and Health, 25*(8 Suppl), 43S–64S. doi:10.1177/0898264313503987.

Zinke, K., Zeintl, M., Eschen, A., Herzog, C., & Kliegel, M. (2012). Potentials and limits of plasticity induced by working memory training in old-old age. *Gerontology, 58*(1), 79–87. doi:10.1159/000324240.

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2014). Working memory training and transfer in older adults: Effects of age, baseline performance, and training gains. *Developmental Psychology, 50*(1), 304–315. doi:10.1037/a0032982.

Educational Application of Working-Memory Training

Tracy Packiam Alloway, Tyler Robinson, and Andrea N. Frankenstein

Introduction

Working memory (WM) is critical for a variety of activities at school, from complex subjects such as reading comprehension, mental arithmetic, and word problems to simple tasks like copying from the board and navigating around school (see Alloway and Copello 2013, for a review). Working memory is also important from kindergarten (Alloway et al. 2005) to the tertiary level (Alloway and Gregory 2013) and is an excellent predictor of academic success, longitudinally (Alloway and Alloway 2010).

WM Training Programs

Given the importance of working memory in learning, it is no wonder that there have been increased research efforts to understand the impact and efficacy of training this skill, particularly in an educational context.[1] In this chapter, we have characterized WM training programs into two categories: those that are narrow in scope and those that are broad in scope. We define narrow-scope WM training programs as those that are very similar to a working memory test. For example, they require the student to remember numbers in backward order or the location of dots in backward order. In contrast, we define broad-scope WM training programs as those that train working memory in the context of broader abilities, such as executive function, attention, or learning skills. We can use an

---

[1] There are other training programs that target related cognitive skills, such as attention or inhibition, but this chapter focuses exclusively on WM training programs.

T.P. Alloway (✉) • T. Robinson • A.N. Frankenstein
Department of Psychology, University of North Florida, Jacksonville, FL, USA
e-mail: t.alloway@unf.edu; t.robinson@unf.edu; a.frankenstein@unf.edu

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_16

example from physical activity to illustrate the difference between these narrow-scope and broad-scope WM training programs. A narrow-scope program typically targets one area—like doing bicep curls to improve the muscle tone in your arms. In contrast, a broad-scope program has a wider application—like running for your general cardiovascular health.

Transfer Effects

When considering the efficacy of WM training, it is important to investigate the nature of *transfer effects*. This refers to whether a training program improves anything other than getting better at the game itself? Practicing a skill will naturally enhance it. This is known as a practice effect. But can the benefits of a WM training program transfer to real world activities; in other words, can you get better at something other than the training program? Transfer effects can be classified as *near transfer* or *far transfer*. Near transfer refers to improvements that are similar to the training program. In the context of WM training programs, a near transfer effect is improved performance on WM tests involving verbal and visuo-spatial stimuli. Some caution should be exercised when considering near transfer effects, as the measures used to assess near transfer effects often share similarities with the activities used in the training programs. As a result, it can be difficult to ascertain whether improvements are the result of practice effects or broader more efficient cognitive functioning.

Consequently, it is especially important to consider far transfer effects, which refer to improvements in skills related to the area of training. In the context of WM training programs, far transfer refers to other executive function skills such as inhibition, updating, and planning, as well as attention and fluid intelligence (IQ). Investigation of far transfer effects can provide some indication of whether training WM can yield improvements in tasks that do not directly mirror the training activities.

Another key factor to consider is whether transfer effects are short-lived or long lasting. In some cases, the improvements may be the result simply of the novelty of using the training program and are not durable, but in other cases, there may be evidence of sustained improvements.

WM Training Programs in an Educational Context

This section explores the efficacy of WM training programs in both near and far transfer effects in the context of education. The following programs are adaptive in nature, which means that the program will either progress to a more challenging level in response to the user's skills or discontinue if the user is unable to successfully complete the tasks.

Narrow-Scope WM Training Programs

One commercial program that has been the focus of a relatively large body of research in this context of WM training is the Cogmed Working Memory Training program (CWMT; www.Cogmed.com). CWMT is an adaptive, 5-week training that can be considered as a narrow-scope program as it mirrors working memory tests. For example, the games in the program include backward digit recall, letter recall, and dot location, and much like a working memory test, the user has to recall numbers in backward order, letters, and the locations of dots in a grid. The target age in the majority of the published research on the CWMT is between 8 and 12 years and has typically been with students with ADHD, though a few studies have been conducted with students with learning difficulties, as well as typically developing students (Kirk et al. 2015; also Schwaighofer et al. 2015).

Research investigating transfer effects with CWMT shows consistent near transfer effects to tests of both verbal and visuospatial WM, in children aged 6–12 years (Kirk et al. 2015). However, far transfer effects are harder to substantiate. Some studies have found far transfer to tests of executive function, such as reasoning and inhibition. However, in other skills related to WM such as attention, findings have been mixed. Teacher ratings of attention and ADHD symptoms are typically not different post-training with CWMT (though see Mezzacappa and Buckner 2010). The pattern of parent ratings of attention and ADHD symptoms are similarly mixed—some have reported differences attributed to the training (e.g., Klingberg et al. 2005), while others have found nonsignificant results in this area (e.g., Green et al. 2012).

Another far transfer skill that is related to working memory is fluid intelligence. While working memory and IQ are closely related (Conway et al. 2002), they represent dissociable skills with unique links to learning outcomes (Alloway and Alloway 2010). To date, there has not been evidence that CWMT improves scores in either verbal or nonverbal IQ tests (Kirk et al. 2015). Similarly, there has not been strong support for far transfer effects of CWMT to learning domains, such as mathematical reasoning or word reading (Holmes et al. 2009), though one study did report improvements in reading comprehension in a special needs population (Dahlin et al. 2008). The persistence of training effects with the CWMT has not been widely investigated; however, Holmes et al. (2009) reported the maintenance of near transfer effects in both verbal and visuospatial WM tests when typically developing students were assessed 6 months later.

Other narrow-scope programs include the Odd Yellow (Van der Molen et al. 2010), which mirrors the Odd-One-Out test. The user is shown three shapes, has to identify the odd-one-out, and then remember the location of the yellow shape on a grid. Students with intellectual disabilities (IQ: 55–85) trained three times a week, during a 5-week period. In the adaptive version, no improvements were found between the training group and the control in either verbal or visuospatial working memory tests (no near transfer effects) and no far transfer effects in tests of fluid intelligence, response inhibition, or scholastic abilities.

Broad-Scope WM Training Programs

There are several broad-scope training programs that train WM in the context of learning activities, such as reading or math. Broad-scope WM training programs are important in light of research linking working memory to a range of scholastic skills. For example, in typically developing children, working memory scores predicted reading achievement independently of measures of phonological skills (Swanson and Beebe-Frankenberger 2004). Working memory is also linked to math outcomes: low working memory scores were closely related to poor performance on arithmetic word problems and poor computational skills (Raghubar et al. 2010).

There are a number of WM training programs that focus on math skills (Titz and Karbach 2014). For example, Cornoldi et al. (2015) gave typically developing 8- to 10-year-olds a problem-solving training program that involved WM. They were presented with a numerical math problem, had to solve it, as well as use WM to recall the problem and words and digits in the task. They reported near transfer effects of improvements in a WM updating task, far transfer to arithmetic problem-solving task, and maintenance effects for both these improvements when the students were tested 3 months later.

Rode et al. (2014) also used a math-based WM training program in mainstream schools. They tested almost 300 third graders and presented them with tasks similar to the operation span task, where they were presented with a math problem to solve (e.g., $2+3=?$) and then a number to remember (e.g., 9). They found near transfer effects to verbal and visuospatial WM tasks, as well as far transfer effects to math, but not reading. They did not measure maintenance effects.

The first author has also published research on a broad-scope WM training program—Jungle Memory—which trains WM in the context of reading, math, and letter recognition. In a pilot study with students with learning difficulties (ages 12–13), half of the students played Jungle Memory, while an active control group received targeted educational support (Alloway 2012). There were near transfer effects to verbal and visuospatial WM tests and far transfer effects to verbal IQ and a standardized math test.

Alloway et al. (2013) conducted a larger study of almost 100 students with learning difficulties (ages 8–12). Students were allocated into one of three groups: Nonactive Control; Active Control, where they trained once a week (WMT-low frequency); and Training group, where they trained four times a week (WMT-high frequency). All three groups were tested on measures of WM, verbal and nonverbal IQ, and standardized measures academic attainment before training and retested on the same measures after training, as well as 8 months later. The data indicate near transfer effects in both verbal and visuospatial WM tests for the high-frequency Training group. There were also far transfer effects in verbal and nonverbal IQ tests, as well as spelling, in the high-frequency Training group. Maintenance effects were reported when students were tested 8 months later.

Neural Activity as a Result of WM Training Programs

What accounts for the transfer effects in WM training programs? One possibility is that the WM training boosts domain-specific skills in language or math that are reliant on long-term memory to improve efficiency. An alternative possibility is that WM training improves general WM functioning in both visual and verbal domains that can also affect related cognitive skills, particularly in an educational context. One avenue to distinguish between these two explanations is look at functional changes in the brain that can be attributed to WM training. While there is limited research on this topic in an educational setting, there is considerably more research on the long-term effects of WM trainings relevant to educational applications (Garavan et al. 2000; Klingberg 2010; Landau et al. 2004, 2007; Moore et al. 2006; Olesen et al. 2004).

With an educational setting in mind, the regions most likely to be involved in training must be taken into consideration. WM is typically assessed with tasks that involve storing, reordering, and recalling sequences numbers, letters, words, or shapes. The neural framework for these tasks, as well as their relationship to WM processing as a whole, is considerably more complex than can be represented by a single measure. For illustration, in both digit and spatial WM tasks, involvement of long-term memory in the form of information chunking was shown early on by Ericsson et al. (1980) and has since been shown that similar increases in activation in the lateral prefrontal cortex exist regardless of the presence of this reorganization into long-term memory (Bor et al. 2003). This indicates that measurable improvement in WM performance can rely to some extent on other networks that do not translate beyond a single specialized task.

While changes to patterns of activation differ across studies, largely dependent on what training and type of working memory is being addressed, persistent changes in activation are reported most consistently in two regions, namely, the dorsolateral prefrontal cortex and regions of the intraparietal cortex (Olesen et al. 2004). Increased activation in these regions as an indicator of improvement in WM capabilities is corroborated by previous research, as individual levels of activation in these areas have been shown to correlate with static levels of WM function (McNab and Klingberg 2008).

Stepping briefly away from multimodal improvement, specific WM trainings show changes in activation, both positive and negative, in occipital regions and precentral sulcus, caudate nucleus, cingulate cortex, and supplementary motor area, related respectively to visual and visuospatial WM training (Garavan et al. 2000; Landau et al. 2004, 2007; Olesen et al. 2004) and updating tasks (Dahlin et al. 2008). As only one of these studies examined cross modal improvement between types of WM tasks (Olesen et al. 2004), little can be said about whether the associated regions, likely specific to the type of sensory processing required for the task, contribute to cross modal improvement in WM performance, as all showed changes in the dorsolateral prefrontal cortex, parietal cortex, or both.

Neural Activity: Increased or Decreased Activity?

It was noted previously that while the regions core to the training and improvement of WM skills appear rooted in the dorsolateral prefrontal cortex and frontoparietal pathways, whether the measured changes in activation in these regions were positive or negative was not always consistent (Jaeggi and Buschkuehl 2012). An intriguing limitation to the plasticity effects associated with working memory training, and one that becomes particularly important in an educational setting, is that the increased activity considered to indicate long-term strengthening of the region in question only appears to occur after considerable time spent training. Counterintuitively, the associated regions of the prefrontal and parietal cortex show decreased, rather than increased, activation after WM training (Garavan et al. 2000; Jansma et al. 2001; Landau et al. 2004, 2007).

The expected increases in activation are, however, apparent in studies in which students undergo cumulative ten or more hours of training, along with varied patterns of increased and decreased activation in other brain regions (Moore et al. 2006; Olesen et al. 2004). Klingberg (2010) postulates that this marked decrease in activation is the result of within-session effects such as priming and learned strategies that reduce the direct load on working memory and that while increases due to training are concurrently present, they have not yet developed to the point at which they overwhelm decreases due to improvements in efficiency. The theory does, however, appear to contradict the findings of Bor et al. (2003) in which the incorporation of chunking to improve efficiency did not result in decreased prefrontal or parietal activation. Regardless, for the purpose of improving long-term results in students, it should be taken into account that training must not only be made broadly applicable but must also persist and repeat to such an extent that long-term improvement can develop, should short-term improvement in performance be explainable by other cognitive strategies.

Neural Activity as a Function of Age

Another consideration that must be taken into account when applying working memory training to students is the age of the students themselves and the developmental differences between grades. As early identification of learning problems is vital to improving student outcomes (Lange and Thompson 2006), the application of working memory training may be even more valuable in younger students. The question then becomes whether the age-related developmental differences between student populations affect the outcomes of working memory training. One study by Ciesielski et al. (2006) compared regions of activation during a categorical *n*-back task between children, ages 6 and 10, respectively, and young adults aged 20–28 years. The children showed reliance on categorically different regions of the brain, with activation most strongly noted in the visual dorsal and sensory-motor pathways, while data from young adult participants indicated predominant use of the ventral prefrontal network. These findings both support and expand upon previous evidence of developmentally related increases in working memory capacity tied to increased activation in frontal and intraparietal regions (Klingberg et al. 2002). With notably different neural framework in use between young children and adults during working memory tasks, the effectiveness of working memory training must be brought into question. However, despite reliance on different regions, the applicability of WM training appears to be clear in children as young as preschool, with visuospatial WM training showing improvements in working memory in children under 5 years of age (Thorell et al. 2009). Further study would be necessary to determine whether the age of first experience with working memory training results in changes to the developmental trajectories of students, or how early exposure affects the transfer of WM processing to the dominant regions in adulthood. For the purposes of educational application, however, the applicability of WM training does not appear to be limited by age.

Conclusion

Ultimately, the goal is to improve WM capacity and performance across the full range of tasks presented to students throughout their academic career, if not beyond. The literature supports the use of WM training in an educational context. Specifically, narrow-scope WM training programs typically yield near transfer effects to verbal and visuospatial WM tasks (Loosli et al. 2012), while broad-scope WM training programs show both near transfer effects and far transfer effects to learning outcomes. These improvements are likely reflected in the noted regions of the dorsolateral prefrontal cortex and frontoparietal pathways previously associated with core WM processing. Of equal importance is evidence that these improvements in WM performance are still present upward of 8 months after the conclusion of the training (Alloway et al. 2013; also Holmes et al. 2009; Klingberg et al. 2005). These findings appear to support the assertion that effectively applying WM training to an educational setting will require targeted training for the base structures of working memory, intentional avoidance of memory techniques that might otherwise inhibit the structural improvement of WM systems, and sufficient time dedicated to training to induce plastic effects in the associated regions of WM processing.

References

Alloway, T. P. (2012). Can interactive working memory training improve learning? *Journal of Interactive Learning Research, 23*(3), 197–207.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology, 106*(1), 20–29.

Alloway, T. P., Bibile, V., & Lau, G. (2013). Computerized working memory training: Can it lead to gains in cognitive skills in students? *Computers & Human Behavior, 29*(3), 632–638. doi:10.1016/j.chb.2012.10.023.

Alloway, T. P., & Copello, E. (2013). Working memory: The what, the why, and the how. *The Australian Educational and Developmental Psychologist, 30*(2), 105–118. doi:10.1017/edp.2013.13.

Alloway, T. P., Gathercole, S. E., Adams, A. M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and other cognitive skills as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology, 23*, 417–426. doi:10.1348/026151005X26804.

Alloway, T. P., & Gregory, D. (2013). The predictive ability of IQ and working memory scores in literacy in an adult population. *International Journal of Educational Research, 57*, 51–56. doi:10.1016/j.ijer.2012.10.004.

Bor, D., Duncan, J., Wiseman, R. J., & Owen, A. M. (2003). Encoding strategies dissociate prefrontal activity from working memory demand. *Neuron, 37*(2), 361–367. doi:10.1016/S0896-6273(02)01171-6.

Ciesielski, K. T., Lesnik, P. G., Savoy, R. L., Grant, E. P., & Ahlfors, S. P. (2006). Developmental networks in children performing a categorical n-back task. *NeuroImage, 33*, 980–990. doi:10.1016/j.neuroimage.2006.07.028.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163–183. doi:10.1016/S0160-2896(01)00096-4.

Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school students: The effect of a training programme focusing on metacognition and working memory. *British Journal of Educational Psychology, 85*(3), 424–439. doi:10.1111/bjep.12083.

Dahlin, E., Nyberg, L., Bäckman, L., & Neely, A. S. (2008). Plasticity of executive functioning in young and older adults: Immediate training gains, transfer, and long-term maintenance. *Psychology and Aging, 23*(4), 720–730. doi:10.1037/a0014296.

Ericsson, K. A., Chase, W. G., & Faloon, S. (1980). Acquisition of a memory skill. *Science, 208*(4448), 1181–1182.

Garavan, H., Kelley, D., Rosen, A., Rao, S. M., & Stein, E. A. (2000). Practice-related functional activation changes in a working memory task. *Microscopy Research and Technique, 51*(1), 54–63. doi:10.1002/1097-0029.

Green, C. T., Long, D. L., Green, D., Iosif, A. M., Dixon, J. F., Miller, M. R., et al. (2012). Will working memory training generalize to improve off-task behavior in children with attention-deficit/hyperactivity disorder? *Neurotherapeutics, 9*, 639–648. doi:10.1007/s13311-012-0124-y.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*(4), F9–F15. doi:10.1111/j.1467-7687.2009.00848.x.

Jaeggi, S., & Buschkuehl, M. (2012). Training working memory. In T. P. Alloway & R. G. Alloway (Eds.), *Working memory: The connected intelligence* (Frontiers in cognitive psychology series). Hove: Psychology Press.

Jansma, J. M., Ramsey, N. F., Slagter, H. A., & Kahn, R. S. (2001). Functional anatomical correlated controlled and automatic processing. *Journal of Cognitive Neuroscience, 13*(6), 730–743. doi:10.1162/08989290152541403.

Kirk, H. E., Gray, K., Riby, D., & Cornish, K. M. (2015). Cognitive training as a resolution for early executive function difficulties in children with intellectual disabilities. *Research in Developmental Disabilities, 38*, 145–160.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences, 17*(7), 317–324. doi:10.1016/j.tics.2010.05.002.

Klingberg, T., Fernell, E., Olesen, P. J., Johneson, M., Gustafsson, P., Dahlström, K., et al. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Child and Adolescent Psychiatry, 44*(2), 177–186. doi:10.1097/00004583-200502000-00010.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781–791.

Landau, S. M., Schumacher, E. H., Garavan, H., & D'Esposito, M. (2007). Regional specificity and practice: Dynamic changes in object and spatial working memory. *Brain Research, 1180*, 78–89. doi:10.1016/j.brainres.2007.08.057.

Landau, S. M., Schumacher, E. H., Garavan, H., Druzgal, T. J., & D'Esposito, M. (2004). A functional MRI study of the influence of practice on component processes of working memory. *NeuroImage, 22*(1), 211–221. doi:10.1016/j.neuroimage.2004.01.003.

Lange, S. M., & Thompson, B. (2006). Early identification and interventions for children at risk for learning disabilities. *International Journal of Special Education, 20*(3), 108–119.

Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working-memory training improves reading processes in typically developing children. *Child Neuropsychology, 18*(1), 62–78. doi:10.1080/09297049.2011.575772.

McNab, F., & Klingberg, T. (2008). Prefrontal cortex and basal ganglia control access to working memory. *Nat Neurosci, 11*(1), 103–107. doi:10.1038/nn2024.

Mezzacappa, E., & Buckner, J. C. (2010). Working memory training for children with attention problems or hyperactivity: a school-based pilot study. *School Mental Health, 2*, 202–208. doi:10.1007/s12310-010-9030-9.

Moore, C. D., Cohen, M. X., & Ranganath, C. (2006). Neural mechanisms of expert skills in visual working memory. *The Journal of Neuroscience, 26*(43), 11187–11196. doi:10.1523/JNEUROSCI.1873-06.2006.

Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience, 7*, 75–79.

Olesen, J. P., Macoveanu, J., Tegnér, J., & Klingberg, T. (2007). Brain activation related to working memory and distraction in children and adults. *Cerebral Cortex, 17*(5), 1047–1054. doi:10.1093/cercor/bhl014.

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences, 20*(2), 110–122. doi:10.1016/j.lindif.2009.10.005.

Rode, C., Robson, R., Purviance, A., Geary, D., & Mayr, U. (2014). Is working memory training effective? A study in a school setting. *PLoS One, 9*(8), 1–8. doi:10.1371/journal.pone.0104796.

Schwaighofer, M., Fischer, F., & Buhner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist, 50*(2), 138–166.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology, 96*(3), 471–491.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106–113. doi:10.1111/j.1467-7687.2008.00745.x.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research, 78*(6), 852–868. doi:10.1007/s00426-013-0537-1.

Van der Molen, M., Van Luit, J., Van der Molen, M., Klugkist, I., & Jongmans, M. (2010). Effectiveness of a computerised working memory training in adolescents with mild to borderline intellectual disabilities. *Journal of Intellectual Disability Research, 54*(5), 433–447. doi:10.1111/j.1365-2788.2010.01285.x.

Changes of Electrical Brain Activity After Cognitive Training in Old Adults and Older Industrial Workers

Michael Falkenstein and Patrick D. Gajewski

Introduction

The goal of cognitive training (CT) for older adults is to improve their performance on cognitive skills that usually deteriorate with age but are important for everyday life performance. In most CT studies, test-like tasks or games which target different cognitive functions were trained via PC (computerized cognitive training; CCT) for an extended time. Recent meta-analyses suggest that CCT leads to improvements of various cognitive functions and also transfers to untrained cognitive tasks or even everyday situations (far transfer) in healthy older adults (Karbach and Verhaeghen 2014; Lampit et al. 2014; Ballesteros et al. 2015; Kelly et al. 2014; Karbach and Kray this volume).

Usually the outcome of CT or CCT is the performance in psychometric or neuropsychological tests. Measures of brain structure or activity go beyond performance in that they reveal the underlying mechanisms which accompany possible changes in test or everyday performance. Among the recent reviews Brehmer et al. (2014) and Bamidis et al. (2014) mentioned brain measures (cf. also Wenger and Shing this volume).

M. Falkenstein (✉)
Leibniz Research Centre for Working Environment and Human Factors at TU Dortmund (IfADo), Dortmund, Germany

Institute for Ageing Learning and Occupation (ALA), Bochum, Germany
e-mail: falkenstein@ifado.de; falkenstein@ala-institut.de

P.D. Gajewski
Leibniz Research Centre for Working Environment and Human Factors at TU Dortmund (IfADo), Dortmund, Germany
e-mail: gajewski@ifado.de

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_17

Most of the measures used in CT studies are based on MRI and fMRI. fMRI has a high spatial but a poor time resolution. Brehmer et al. (2014) provided a comprehensive review on such changes due to different types of CT in healthy older adults. The electroencephalogram (EEG) records and measures this activity from the human scalp during task performance. Complementary to fMRI, the EEG has a high time but a poor spatial resolution. Surprisingly there are only a few studies that used the EEG to evaluate effects of CT in healthy older adults, and they are almost neglected in the current reviews (but see Green et al. this volume). Thus, the first part of the present chapter wants to fill this gap by providing a comprehensive overview about EEG-based CT studies in healthy older subjects.

In the second part, some results of an EEG-based CT study with older industrial workers are presented. There is converging evidence that long-term cognitively undemanding job demands increase the age-related cognitive decline (e.g., Finkel et al. 2009). Such unchallenging jobs are much more frequent than cognitively demanding ones. The possibility to use CT to improve cognitive abilities in older workers with cognitively undemanding jobs is of high relevance to enhance their mental fitness and health and thus also their employability.

CT Studies with Older Adults Using EEG-Based Methods

The EEG records the neural activity of cortical and some subcortical sources with electrodes placed on the scalp. Functional activity is either reflected in oscillations at specific frequencies and locations, such as frontal theta activity which has been related to top-down control processes (Onton et al. 2005) and which is usually reduced in older subjects (Cummins and Finnigan 2007).

The other type of functional EEG activity are so-called event-related potentials (ERPs) which can be extracted by averaging EEG segments that are time locked to specific events, such as stimuli or responses. The ERP components are related to sensory, cognitive, or central motor processes. The brain sources of ERPs can be estimated with source analysis software like LORETA (Pascual-Marqui et al. 1994) . In older adults some cognitive ERP components are attenuated or delayed (e.g., Gajewski et al. 2010b), while ERPs after irrelevant stimuli are often enhanced (Hahn et al. 2011). In the following the existing CT studies using EEG-based measures are shortly reported.

Falkenstein, Gajewski, and colleagues were the first to use ERPs in a CT study. In their "Dortmund training study," 150 healthy older adults were randomized to three different group interventions, CT, physical training, stretching and relaxation training (active control group), and a no-contact control group (Gajewski et al. 2010a; Gajewski and Falkenstein 2012; Wild-Wall et al. 2012). Training duration was equal for the three active groups (two sessions of 90 min per week for 16 weeks). For the CT group paper and PC-based tasks were selected from different commercial products so that each targeted cognitive function was trained with several different tasks. The difficulty of the tasks was adapted and adjusted to the current individual performance of the trainees. A battery of paper- and PC-based psychometric tests that address cognitive control functions was administered before and after the training. During the eight PC-based tasks, the EEG was recorded and ERPs were computed. Some of the tasks were insensitive to CT (e.g., antisaccade task, auditory distraction task). However, behavioral and ERP effects due to CT were seen in other executive tasks mainly for the CT group such as visual search (Wild-Wall et al. 2012), task switching (Gajewski and Falkenstein 2012), and Stroop and 2-back (unpublished data).

The general pattern of the ERP results was an amplitude increase of ERP components related to cognitive processes such as preparation (CNV), task-related stimulus processing (P2), response selection (N2), resource allocation and working memory (P3b), and error detection (Ne/ERN). In contrast, early sensory ERPs were not affected. However, the ERP effects due to CT differed across the tests. For example, in the switch task increases of the N2, P3b and Ne were observed which were accompanied by a reduction of mixing costs in accuracy and intraindividual RT variability (Gajewski and Falkenstein 2012). In the visual search task, the P2 was enhanced which was accompanied by an increased target detection rate. Source analysis (LORETA) located this effect in lingual and parahippocampal brain areas which are linked to visual feature processing (Wild-Wall et al. 2012). The enhancement of the CNV after CT in the switch task is of particular interest because it reflects a compensatory mechanism. A strong preparation (i.e., a large CNV) is related to low error rates (Hohnsbein et al. 1998). Hence, the enhancement of the CNV is likely one reason for the reduction of the error rate.

Anguera et al. (2013) had their subjects play a dual task video game which consisted of tracking while responding to traffic signs with adaptive difficulty for 12 sessions. An active control group only trained the subtasks, while a third group received no training. Only after the dual task training, multitasking costs in a nonadaptive version of the game were reduced, with gains persisting for six months. Further, working memory and sustained attention were enhanced. In the EEG, frontal theta power and frontal-posterior theta coherence, which were attenuated before the training, were found to be enhanced but only after the dual task training. Notably, the dual task training led to changes in the neural processing of signs that reached a level comparable to neural activity patterns observed in younger adults.

O'Brien et al. (2013) trained eleven old subjects with a speed of processing (SOP) training aimed at enhancing perceptual processing of visual stimuli in visual attention tasks. SOP training primarily involves practice of perceptual processing with exercise difficulty adapted to the individual user. Before and after the training, a visual search task was administered and ERPs determined. Selective attention to a target was enhanced after the CT compared to a no training control group. In the ERPs the amplitudes of the N2pc and P3b were increased after training, reflecting enhanced focusing of attentional and processing capacity allocation due to the training. The authors conclude that SOP training may be successful in counteracting age-related declines in selective attention.

As mentioned above, older adults have deficits in ignoring distracting irrelevant information. Mishra et al. (2014) conducted two parallel experiments with older rats and humans. They administered a cognitive training with adaptive difficulty of distinguishing between auditory targets and distractors. Training resulted in enhanced discrimination abilities in both species. After CT, neural responses to distractors in the auditory cortex were selectively reduced in both species, mimicking the behavioral effects. Training gains generalized to group and individual level benefits in aspects of working memory and sustained attention. Moreover, frontal theta measures of top-down engagement with distractors were selectively restrained in trained humans. This study shows converging cross species evidence for a training-induced improvement of distractor control.

Rose et al. (2015) administered a CT aimed at improving prospective memory (PM) for 12 sessions. One group received music training and a no-contact group served as active and passive control. Performance and ERPs during a lab-based PM task, real-world PM, and instrumental activities of daily living were assessed before and after training. Importantly, the CT produced far transfer to performance on real-world PM and activities of daily living. The ERPs revealed a reduction of a negative ERP component which is likely related to the processing of PM cues, which suggests more automatic PM retrieval.

In a recent study, Gaál and Czigler (2016) administered a task-switching training to young and old subjects in which the difficulty was individually adjusted. The training led to strong performance increases in the old subjects up to the level of the young subjects. In the ERP this performance improvement was accompanied by an increase of the P3 component after both cues and targets in the older subjects.

In summary the EEG-based CT studies showed increased frontal theta activity after a complex dual task training which suggests the improvement of control. In contrast frontal theta activity was reduced after an auditory discrimination training suggesting less need for control. This reduction of control was paralleled by a selective reduction of distractor processing, as revealed in auditory ERPs. Generally (with one exception), the ERP-based studies showed increases of “cognitive” components such as the P3, while latencies remained unaffected. This was usually paralleled by a reduction of error rate but not a speeding of responses.

EEG-Based Studies with Older Industrial Workers

Challenging work represents an important cognitive stimulation to protect age-related decline or to enhance compensatory mechanisms (Wild-Wall et al. 2009) which may reduce the risk of cognitive decline in older age (Andel et al. 2005). In a longitudinal study with about 3000 workers, Marquié et al. (2010) showed that the more cognitively stimulating the work, the higher the performance in tests of episodic memory, attention, and speed of processing and the more favorable the change of these functions over a 10-year follow-up.

The first part of the project PFIFF, a program for improving cognitive abilities in older employees, aimed at investigating cognitive functions in older industrial workers with low vs. high stimulating work characteristics in a cross-sectional design (Gajewski et al. 2010b). Four groups of industrial workers ($n = 91$) of a big car factory participated in the study. One group consisted of older workers (mean age 52) and the other of younger workers (mean age 22). Both groups were again divided: one group worked flexibly in areas such as service and maintenance, while the other worked in the repetitive assembly line production. In other aspects the groups were well matched for age, education, and health status. The workers were administered a series of EEG-supported tests as in the "Dortmund training study." The most difficult task was a memory-based task-switching paradigm. The comparison between both groups of the old adults showed that flexibly working older employees responded faster and produced lower error rates than the older assembly line employees. This was accompanied by enhancements of the CNV, the P3b, and the Ne/ERN. These results support the findings in the literature reported above, suggesting a positive influence of long-term flexible and challenging job characteristics on performance in a difficult novel task. The ERP changes reveal in detail the cognitive functions that differed between employees with repetitive and flexible work, namely, preparation, working memory, and error processing.

In a subsequent longitudinal intervention study, CT was administered to 120 middle-aged industrial workers (mean age 47 years) with long-term repetitive work from the same factory. The sample was subdivided into two groups with 60 workers each which completed the study successively. The subgroups were randomly assigned either to immediate CT or a waiting control group that received CT later. Participants were trained with a similar supervised variable CT and CCT as used in the "Dortmund training study" for 3 months (two sessions of 90 min per week). The training was evaluated with paper-based tests and the EEG-supported memory-based task-switching task as administered in the preceding cross-sectional study.

Compared to the waiting control group, the trainees improved their performance in a number of psychometric paper and pencil tests. The results of the task switching showed also improvements of cognitive performance after CT, particularly a decrease of error rates, suggesting improved maintenance of a complex task sequence in working memory. The behavioral benefits were accompanied by a number of electrophysiological changes, in particular an increase of the N2 and the Ne/ERN due to the CT. This pattern of results persisted even three months after the training was finished. In contrast no changes in the waiting control group were found at this time point. However, after this group had also received CT, the same performance improvements and ERP changes were observed as in the cognitive training group before (Gajewski et al. in preparation).

The findings suggest that job and/or aging-related deficits in certain cognitive processes can be ameliorated by CT.

General Discussion and Conclusion

Summary of the Results

In the EEG-based CT studies enhancements of processes have been consistently reported. With respect to EEG oscillations, frontal theta activity and frontal-parietal coherence were enhanced after a dual task CT, which suggests an increase of control. In contrast, theta and hence cognitive control was reduced after a simple discrimination training which led to a decrease of the ERP after irrelevant stimuli. This also suggests that the processing of distracting stimuli, which is usually enhanced in older individuals, can be attenuated due to CT.

Generally, ERPs after task-relevant stimuli show increased amplitudes of cognitive ERP components after CT, while latency reductions have not been observed by now. The amplitude increases were paralleled by improvements of performance quality (reduced error rates) but not of speed (no change of RTs). The changes were generally restricted to later components which reflect cognitive and response monitoring processes, while early components reflecting sensory processes did hardly change. The EEG studies also confirm the findings of behavioral CT studies that an adaptive difficulty of the CT appears to be important for the success. These conclusions are of course preliminary and have to be strengthened in future CT studies with EEG methods.

Benefits of EEG-Based Measures in CT Studies

The crucial advantage of brain measures over mere behavioral measures is that they can reveal changes of brain structure and function underlying performance changes due to CT. Brain measures can also be used to analyze why certain individuals profit more than others from a CT. Differences in brain changes between successful and unsuccessful trainees may help to adapt the training in a way to improve the success also in the latter. In their review Brehmer et al. (2014) stated that such an approach might provide useful information for developing individualized and more specific training programs that target factors related to individual deficits or differences in performance and its neural correlates. Brain measures can be used to track those changes in time and can also disentangle the interplay of different processes and their development during CT. For example, in the Mishra et al. (2014) study, the processing of irrelevant stimuli was reduced due to CT which enabled a reduction of cognitive control. Finally, brain measures can reveal strategic or compensatory mechanisms, such as an enhancement of preparation (CNV), as observed in the Dortmund training study which was paralleled by a reduction of error rates. Such results also show that behavioral measures are important if not indispensable to explain changes in brain measures and vice versa.

In future studies this potential of brain derived in addition to behavioral measures should be more fully exploited. In particular, brain measures should be used to investigate differential development of brain changes in the course of CT in young and older trainees in dependence of their training success and further influence factors such as pre-training performance. This could clarify why some old subjects profit more from CT than others, as also seen in the PFIFF study. It could be that successful trainees show similar brain changes than young ones or change their neural pattern toward that of young subjects or rather recruit additional processes to be successful. For example, older subjects often show a larger CNV than young subjects in difficult but not easy tasks (Wild-Wall et al. 2007). This might also happen in the course of CT, as shown in the Dortmund training study. Changes due to CT appear to develop rather early in the course of the training. Hence, in future studies the assessment of brain functions should be performed several times during the course of CT and also after the training in follow-up sessions. Such follow-up measures should consider whether the trainees continued CT in a self-directed manner or not, and if not, how long the training effects persist.

Despite their clear benefits, brain measures are not easy to achieve in comparison to behavioral measures. Also it should be considered which of the measures are appropriate and affordable. MRI and EEG-based methods appear to have complementary benefits: while ERPs can reveal changes in the timing and strength of single processes, MRI-based methods have better access to subcortical structures and can reveal changes of brain networks due to training. Ideally the two method domains should be combined. This extends the suggestion of Brehmer et al. (2014) who claimed a multimodal approach by combining several imaging methods in future CT studies. We recommend using EEG-based measures in such combinations or also as single method. EEG is easy and flexible to apply, for example, in field studies and could be easily used in factories. Moreover, they are nonintrusive and well tolerated by older subjects and do not require large changes in the psychometric test settings. The comfortable application is also well suited to administer multiple assessments in the course of a CT which is highly useful to track CT-related changes in time. Therefore, EEG-based methods should be more often applied in future CT studies.

CT Studies with Industrial Workers

Among the most important results reported in the present chapter is the successful improvement of cognitive functions in older workers with long-term repetitive work in the PFIFF project. This shows that adverse environmental influences on cognitive aging such as unchallenging work can be counteracted by CT.

In the PFIFF project (as well as in the "Dortmund training study"), CT was administered in groups by an experienced trainer, and care was taken to provide individually adapted difficulty and difficulty increase of the trained tasks. In future CT studies, different formats should be explored with respect to compliance, training success, and change of brain measures. For example, a continuously teacher-guided

CT (as also suggested by Lampit et al. 2014) is expensive, so future CT studies should explore whether an initial guidance with subsequent self-administered CT yields similar effects as a full teacher-guided CT. Also the optimum format of CT is unknown, and future CT studies should investigate the impact of features like adaptivity and feedback. Usually CT is rather short, and the three months duration in the PFIFF study (or four months in the "Dortmund training study") might have been too long and may have even resulted in weariness. Future studies with workers should compare CT formats of different length and assess brain and behavioral changes several times. Such studies should also include younger in addition to older workers, and differences in their pre-training cognitive states should be considered.

In particular, future CT studies with workers should focus on the influence of work-related factors that likely affect cognition (such as type of work, control about work process, and social relations) on the success of the CT. For example, shift work, and in particular night shifts, is known to affect cognition (Ansiau et al. 2008). Hence, in future studies participants with and without night shift should be included in CT trials and different effects assessed. A simple method to enrich the working environment is rotation of work places and job assignment. Future longitudinal studies should assess whether rotation improves cognition compared to non-rotation in older workers. In such studies also the effects of rotation and CT could be compared.

One of the most intriguing questions is whether an improvement in cognitive functions due to CT in workers also transfers to work-related behavior. By now there are only very few reports on transfer of CT benefits to real life (e.g., Rose et al. 2015). In the PFIFF project, the CT improved performance and brain measures in a complex test task (the memory-based switch task). As no far transfer tasks related to the work were used, no direct conclusions can be drawn from these results regarding the employability of elderly workers. Nevertheless, the observed CT-induced improvements of cognition and performance in this task may indicate enhanced learning ability and self-confidence and thereby improve performance in novel or complex working situations. Such situations, e.g., the change of a complex machine tool under time pressure, are common in modern work environment and are a principal source of stress. In future studies it should be explored whether CT leads to better self-reported and supervisor-reported performance and reduced stress particularly in such situations.

In summary, CT appears a most promising tool for improving mental fitness and employability in older workers. Future CT studies in occupational environments should evaluate far transfer by measurements of work efficiency, individual performance at work, risk of workplace injuries, and work-related illness.

Acknowledgments We want to thank Christiane Westedt and Ludger Blanke for their invaluable organizational and technical support in the EEG-based studies. Moreover, we are grateful to Ute Lobisch for improving style and legibility of the draft and for her committed work with text and literature formatting.

References

Andel, R., Crowe, M., Pedersen, N. L., Mortimer, J., Crimmins, E., Johansson, B., et al. (2005). Complexity of work and risk of Alzheimer's disease: A population-based study of Swedish twins. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 60*(5), 251–258.

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., et al. (2013). Video game training enhances cognitive control in older adults. *Nature, 501*(7465), 97–101.

Ansiau, D., Wild, P., Niezborala, M., Rouch, I., & Marquie, J. C. (2008). Effects of working conditions and sleep of the previous day on cognitive performance. *Applied Ergonomics, 39*(1), 99–106.

Ballesteros, S., Kraft, E., Santana, S., & Tziraki, C. (2015). Maintaining older brain functionality: A targeted review. *Neuroscience and Biobehavioral Reviews, 55*, 453–477.

Bamidis, P. D., Vivas, A. B., Styliadis, C., Frantzidis, C., Klados, M., Schlee, W., et al. (2014). A review of physical and cognitive interventions in aging. *Neuroscience and Biobehavioral Reviews, 44*, 206–220.

Brehmer, Y., Kalpouzos, G., Wenger, E., & Lovden, M. (2014). Plasticity of brain and cognition in older adults. *Psychological Research, 78*(6), 790–802.

Cummins, T. D., & Finnigan, S. (2007). Theta power is reduced in healthy cognitive aging. *International Journal of Psychophysiology, 66*(1), 10–17.

Finkel, D., Andel, R., Gatz, M., & Pedersen, N. L. (2009). The role of occupational complexity in trajectories of cognitive aging before and after retirement. *Psychology and Aging, 24*(3), 563–573.

Gajewski, P. D., & Falkenstein, M. (2012). Training-induced improvement of response selection and error detection in aging assessed by task switching: Effects of cognitive, physical, and relaxation training. *Frontiers in Human Neuroscience, 6*, 130.

Gajewski, P. D., Wild-Wall, N., Schapkin, S. A., Erdmann, U., Freude, G., & Falkenstein, M. (2010a). Effects of aging and job demands on cognitive flexibility assessed by task switching. *Biological Psychology, 85*(2), 187–199.

Gajewski, P. D., Wipking, C., Falkenstein, M., & Gehlert, T. (2010). *Dortmunder Altersstudie: Studie zur Förderung der Hirnleistungsfähigkeit bei Älteren (Forschungsbericht VV04)*. Berlin: Die deutschen Versicherer (GDV).

Gaál, Z., Czigler, I. (2016). Task-switching training and transfer: age-related effects on late ERP components. *Journal of Psychophysiology* (in press).

Hahn, M., Wild-Wall, N., & Falkenstein, M. (2011). Age-related differences in performance and stimulus processing in dual task situation. *Brain Research, 1414*, 66–76.

Hohnsbein, J., Falkenstein, M., & Hoormann, J. (1998). Performance differences in reaction tasks are reflected in event-related brain potentials (ERPs). *Ergonomics, 41*(5), 622–633.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*(11), 2027–2037.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta-analysis. *Ageing Research Reviews, 15*, 28–43.

Lampit, A., Hallock, H., & Valenzuela, M. (2014). Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. *PLoS Medicine, 11*(11), e1001756.

Marquié, J. C., Duarte, L. R., Bessieres, P., Dalm, C., Gentil, C., & Ruidavets, J. B. (2010). Higher mental stimulation at work is associated with improved cognitive functioning in both young and older workers. *Ergonomics, 53*(11), 1287–1301.

Mishra, J., de Villers-Sidani, E., Merzenich, M., & Gazzaley, A. (2014). Adaptive training diminishes distractibility in aging across species. *Neuron, 84*(5), 1091–1103.

O'Brien, J. L., Edwards, J. D., Maxfield, N. D., Peronto, C. L., Williams, V. A., & Lister, J. J. (2013). Cognitive training and selective attention in the aging brain: An electrophysiological study. *Clinical Neurophysiology, 124*(11), 2198–2208.

Onton, J., Delorme, A., & Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage, 27*(2), 341–356.

Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1994). Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. *International Journal of Psychophysiology, 18*(1), 49–65.

Rose, N. S., Rendell, P. G., Hering, A., Kliegel, M., Bidelman, G. M., & Craik, F. I. (2015). Cognitive and neural plasticity in older adults' prospective memory following training with the Virtual Week computer game. *Frontiers in Human Neuroscience, 9*, 592.

Wild-Wall, N., Falkenstein, M., & Gajewski, P. D. (2012). Neural correlates of changes in a visual search task due to cognitive training in seniors. *Neural Plasticity, 2012*, 529057. http://dx.doi.org/10.1155/2012/529057.

Wild-Wall, N., Gajewski, P. D., & Falkenstein, M. (2009). Kognitive Leistungsfähigkeit älterer Arbeitnehmer. *Zeitschrift für Gerontologie und Geriatrie, 42*, 299–304.

Wild-Wall, N., Hohnsbein, J., & Falkenstein, M. (2007). Effects of ageing on cognitive task preparation as reflected by event-related potentials. *Clinical Neurophysiology, 118*(3), 558–569.

Cognitive Training in Mild Cognitive Impairment

Sylvie Belleville, Benjamin Boller, and Laura Prieto del Val

Introduction

Dementia is diagnosed when a pervasive cognitive decline significantly affects the autonomy of the individual. Although dementia can have many causes, Alzheimer's disease (AD) is recognised as the most common aetiology in older adults. The cognitive changes that characterise AD are progressive and the disease evolves over up to 20 years before patients meet criteria for dementia. During this extensive prodromal phase, symptoms are dormant or very mild. The term mild cognitive impairment (MCI) has been used to refer to individuals who may be in a pre-dementia phase of AD and who have an elevated likelihood of progressing to the disease. The presence of a subjective complaint, which indicates that the individual is aware of their cognitive changes, is a main characteristic of MCI. For this reason, and because the ability to learn new skills and strategies is preserved in this population, persons with MCI are particularly well suited to benefit from cognitive stimulation, which could significantly improve their quality of life. This chapter is a qualitative review of the studies measuring the impact of cognitive training in persons with MCI. Section "Mild Cognitive Impairment as a Target for Cognitive Training" will introduce the concept of MCI and the reasons why this phase is believed to be appropriate for cognitive training. Section "Memory Training" will present studies on

---

S. Belleville (✉) • B. Boller
Research Center, Institut Universitaire de Gériatrie de Montréal
and Université de Montréal, Montréal, QC, Canada
e-mail: sylvie.belleville@umontreal.ca; benjamin.boller@umontreal.ca

L.P. del Val
Department of Physiology, Anatomy, and Cellular Biology,
Pablo de Olavide University, Sevilla, Spain
e-mail: lpridel@upo.es

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_18

memory training, section “Training of Attentional Control” will present studies on attentional or executive training, and section “Training Imbedded in Real Life: Virtual Reality and Leisure Approaches to Cognitive Training” will present strategies to promote generalisation of the acquired skills in everyday life. Finally, studies relying on neuroimaging will be presented, followed by models of the training-induced brain changes.

Mild Cognitive Impairment as a Target for Cognitive Training

MCI represents a cognitive decline that is greater than what is considered normal based on the individual’s age and educational level, but that is not significant enough to limit independence in daily life activities and meet criteria for dementia. Though the original MCI concept required the presence of memory difficulties, its current definition includes impairment in non-memory domains and the possibility that MCI may progress to neurodegenerative diseases other than AD (Albert et al. 2011). A person with MCI can be categorised based on whether one or more cognitive domains are affected (i.e. single vs. multiple domain MCI) and whether they are amnestic (a-MCI) or non-amnestic MCI. The a-MCI subtype has received considerable attention since it is the subtype that most likely represents prodromal AD.

Appropriate models of cognitive training for MCI should rely on an understanding of which functions are impaired and which are preserved. Cognitive functions have been greatly researched in MCI and a pattern characteristic of MCI symptomatology is emerging (Belleville et al. 2008). Episodic memory, which is the ability to encode and retrieve new information that is embedded in a spatio-temporal context, appears to be the cognitive component that is the most impaired. Working memory, the ability to manipulate maintained information, is also impaired in a-MCI, whereas short-term memory and implicit memory seem to be preserved. Executive functions, on the other hand, including response inhibition, switching, cognitive flexibility and abstract thinking seem to diminish in MCI.

Many factors make MCI a suitable target population for cognitive training: (1) given that pharmacological treatment such as cholinesterase inhibitors (ChEIs) has not been successful in MCI (Petersen et al. 2005), non-pharmacological treatment may be an appropriate and risk-free alternative to improve cognitive functions; (2) individuals with MCI maintain a certain degree of cognitive plasticity that allows them to learn and apply new strategies; (3) symptomatic treatment would produce the maximum benefit when applied at the earliest time point of the AD process; (4) observational studies indicate that cognitive stimulation can have an impact on cognitive decline and dementia; (5) a cognitively stimulating lifestyle has found to be among the most important protective factors against dementia (Barnes and Yaffe 2011).

One major support for cognitive stimulation is that it protects against age-related cognitive decline and dementia. Education, learning new things or enjoying a challenging job are mentally invigorating and represent life-course models of mental stimulation. There is growing evidence that differences in cognitive lifestyles affect age-related cognitive decline and resistance to neurodegenerative diseases. Most of the evidence comes from observational studies examining the association between different lifestyle factors and cognitive decline or dementia. Barnes and Yaffe (2011) indicated that cognitive inactivity, most often measured with level of formal education, was associated with a 59 % increased risk of developing AD and was estimated to account for about 19 % of AD cases worldwide. The authors estimated that reducing the prevalence of low education attainment by 10 % would reduce the incidence of AD by about 534,000 cases. Thus, observational studies indicate that cognitive stimulation across the lifespan determines differences in the risk for age-related neurodegenerative diseases and that reducing cognitive inactivity has the potential to substantively affect the prevalence of cognitive impairment.

Memory Training

Episodic memory is the most severely affected cognitive function and the main complaint in MCI. Thus, cognitive training as a way of promoting the maintenance and improvement of episodic memory in older adults with MCI has attracted major attention. Memory training programmes typically focus on teaching strategies to encourage richer encoding or to facilitate retrieval (see also Wenger and Shing this volume), and they rely on aspects of memory that are relatively well preserved in MCI such as semantic knowledge, visual imagery or implicit retrieval. A large number of mnemonic strategies and procedures have been used including errorless learning, spaced retrieval, mind mapping, cueing, semantic organisation and elaboration, mental imagery, and the method of loci. Some are quite effortful and demand strong metacognitive abilities such as the method of loci, which requires the individual to produce an interactive image between items he/she is to learn and a series of loci in a familiar environment. Other procedures rely on more automatic memory systems such as space retrieval, where information is recalled multiple times at increasingly longer intervals. Most studies employ a combination of mnemonic strategies so as to provide patients with a broad set of tools. Most programmes comprise a face-to-face intervention in which a therapist teaches these strategies and provides guidance and practice on either an individual or small-group basis.

Several studies have found that these strategies improve proximal memory measures, whether they are tested with immediate or delayed free recall of words (Belleville et al. 2006; Olchik et al. 2013), recognition (Herrera et al. 2012), event-related prospective memory (Tappen and Hain 2014) or face-name associations (Belleville et al. 2006). Some of them show that an active control comparison group (Herrera et al. 2012; Olchik et al. 2013; Tappen and Hain 2014) benefited less than the group receiving memory training, suggesting that performance gains are not entirely attributable to non-specific stimulation. Subjective memory seems to also benefit from memory training when the programme introduces the notion that older adults can cope with memory problems or when cognitive restructuring of memory-related beliefs is provided (Belleville et al. 2006; Rapp et al. 2002). Targeting these components in MCI is relevant, as it can contribute to increasing self-efficacy—the perception that individuals have control over their memory—and can reduce MCI-related anxiety and depression. Overall, these studies indicate that memory interventions are promising and can increase memory performance in persons with MCI. They also suggest that the benefits can generalise to noncognitive domains.

Some of these studies have imbedded memory training within broader multimodal interventions to maximise the cognitive training effect (Belleville et al. 2006; Kinsella et al. 2009; Schmitter-Edgecombe and Dyck 2014). Belleville and collaborators (2006) developed a multifactorial approach to be used with healthy older adults and persons with MCI (*Méthode d'entraînement pour une mémoire optimale*, MEMO). The programme teaches different mnemotechniques (e.g. method of loci, face-name association, interactive imagery, text hierarchisation, semantic elaboration) and includes training on attention and visual imagery abilities. It also provides general psychoeducational information on cognitive ageing and lifestyle factors and includes a number of features to promote self-efficacy and generalisation. This programme successfully resulted in improvement on objective episodic memory. There was also some transfer to subjective memory measures and on well-being. Kinsella and colleagues (2009) developed a multifactorial intervention that involved memory strategies, lifestyle, education and psychotherapeutic techniques and that included family partners. They showed improvement on everyday memory, suggesting a generalisation of the effect to broader domains and contexts. Schmitter-Edgecombe and collaborators (2014) reported similar results with a programme that involved care-partners and comprised an educational workshop, multifamily memory strategy training, and problem-solving sessions. The involvement of family partners may facilitate the transfer of learned strategies to everyday functioning by providing support and feedback to their relatives with MCI.

Multimodal computerised training programmes have also shown interesting results when applied to individuals with MCI. These programmes are designed to target a general population of brain-damaged patients and typically include exercises for a wide range of cognitive functions (e.g. attention, perception, language, gnosias, calculation) in addition to memory. Rozzini et al. (2007) found that treatment with ChEIs alone did not reduce memory impairment in MCI subjects but that combining computerised cognitive training with ChEIs resulted in significant memory improvements. Whether computerised training is as effective as face-to-face training has not yet been directly tested. Notably, however, Gaitán and colleagues (2013) tested the efficacy of multimodal computerised training with MCI persons who already received conventional face-to-face cognitive training and found that it did not produce further memory improvement. There is no strong evidence thus far that multimodal computerised training leads to a significant transfer to complex or daily activities.

Despite the positive effects of memory training described above, some randomised-controlled studies have reported negative findings. For instance, Unverzagt et al. (2007) found no benefit from memory training in a memory-impaired subgroup from the ACTIVE cohort. Vidovich and collaborators (2015) reported improvement on attentional control and quality of life following memory training in MCI but no improvement on primary cognitive outcomes. The lack of systematic improvement makes it difficult to determine whether cognitive training interventions are able to affect a broad set of memory-related activities. A range of factors could explain the negative findings, for instance, it may be due to the fact that the selected outcome is insufficiently sensitive to change or is not sensitive to the processes improved by the intervention. Furthermore, the training format may also be an issue. Thus, there is a need for more studies aiming to disentangle the characteristics of an effective memory training programme in MCI and its impact on complex memory-related activities. There are interesting avenues researchers could take: one may be to provide interventions that include additional cognitive or noncognitive components; another would be to involve family partners in the intervention programme.

Training of Attentional Control

Attentional control and executive functions are highly involved in everyday life and executive impairment is predictive of disability in older adults. Surprisingly, very few studies have focused on exercising these comprehensive abilities. Yet, there is evidence that training can improve attentional control in older adults (Karbach and Kray this volume). For instance, Strobach and colleagues (2015) found that hybrid dual-task training, i.e. training with blocks that contain both dual-task and single-task trials, improved coordination skills. The authors also found that the effect was still present when tested with slightly different tasks, suggesting a near transfer of improved coordination skills. Divided attention capacities can be trained using variable priority training as opposed to fixed priority training. In both cases, participants practise divided attention tasks, but in the variable priority training, individuals are also asked to prioritise one task over the other and to vary their attentional priority across different blocks of practice. Many authors reported that variable priority training is more effective in improving dual tasking than fixed priority (Bier et al. 2014; Gagnon and Belleville 2011; Kramer et al. 1995; Lee et al. 2012; Voss et al. 2012) perhaps because it allows individuals to practise top-down regulatory control and hence increases self-control capacities over attention (Bier et al. 2014). Gagnon and Belleville (2012) compared the efficacy of variable and fixed priority training in persons with MCI who experience difficulties with executive control and found that variable priority increased dual-tasking capacities when compared to fixed priority training. These results suggest that training attention with programmes that promote self-monitoring and metacognition can increase dual-tasking abilities in persons with MCI.

Training Imbedded in Real Life: Virtual Reality and Leisure Approaches to Cognitive Training

Ultimately, the goal of cognitive training is to ensure that it results in significant changes in patients' lives (Taatgen this volume). Traditional training programmes are extremely variable in their ability to show far or even near transfer effects. Complex cognitively stimulating activities such as volunteer work, learning new languages or engaging in interesting hobbies have the potential to meet these requirements. These activities involve learning a range of cognitive challenges that are of increasing complexities. They promote continuous learning, are pleasurable and hopefully promote engagement, motivation and transfer to everyday life, particularly in those who may not feel comfortable with academic activities. They are also multimodal by nature, as they involve social interactions and require that older adults explore new environments and be physically active. Interestingly, observational studies have identified these types of activities as being protective against cognitive decline and dementia. Programmes based on similar activities have been shown to promote cognition in older adults. For instance, the SYNAPSE project (Park et al. 2014), which involves photography and/or learning how to quilt, was found to improve memory when compared to a placebo condition. In the Baltimore Experience Corps study (Carlson et al. 2008), in which older adults tutored elementary school pupils, improvement was found in cognition, health and well-being. Within the Canadian Consortium on Neurodegeneration in Aging programme, the ENGAGE programme will combine formal memory and attentional training strategies with leisure activities (Spanish or music lessons) and assess whether it improves cognitive, psychosocial and brain variables in persons with subjective cognitive decline (SCD), i.e. individuals who worry about their cognition but who are not cognitively impaired according to conventional neuropsychological tests. Because they are rooted in the community and are enjoyable, it is expected that cognitive programmes that are embedded in real life such as ENGAGE, SYNAPSE or Experience Corps will have more enduring effects, that their efficacy will transfer more readily to everyday life and that it will be easier to offer them largely.

Developments in technology can also contribute to introducing interventions into real-life settings and promote transfer. Virtual reality (VR), for instance, allows the creation of three-dimensional, computer-generated, interactive environments. VR reproduces daily life situations into near-realistic environments that simulate the impression of being there, and a few studies have used VR to potentiate cognitive training effects in persons at risk of AD. For instance, Man and collaborators (2012) used a virtual environment that simulated a home setting and a convenience store to train the memory of individuals with MCI. VR training involved memorising virtual objects and retrieving them within the virtual environment with a range of presentation modalities, distractors and levels of complexity, and its efficacy was compared with a face-to-face memory training condition. The results showed greater memory performance after having trained in the VR condition but better subjective memory following the face-to-face condition. This suggests that while the memory of individuals with MCI may benefit from the enhancing effects of being trained in a virtual environment, traditional approaches may be more appropriate for addressing self-efficacy and metacognition. Of note, most studies on virtual cognitive training use desktop computers with a two-dimensional screen interface and a mouse or keyboard to navigate the virtual environment, which may lead to a low degree of immersion in the virtual environment and may not provide enough interactivity. This might explain why the only VR-based cognitive training study that examined transfer to real-life activities reported no benefit on measures of activities of daily life, despite the expectation that VR would favour generalisation. Thus, future VR-based training should rely more on immersive multisensory environments such as those provided by VR goggles or whole-body environment exploration.

The Effect of Training on Brain Structure and Function

Brain imaging can establish the neural mechanisms by which training enhances cognitive functioning and indicate the training-induced neural changes (Guye et al. this volume). It can show whether the intervention modified specialised regions, i.e. regions that are normally involved in the task, or activated alternative brain regions, i.e. regions that are not normally active during the task and that are newly engaged. Brain imaging can also indicate whether the intervention focused on improving the function or brain region impaired (restorative effect) or relied on the intact functions and network (compensatory effect).

The few studies that have explored neural activity changes following cognitive training in MCI suggest that it can have both compensatory and restorative effects. Belleville and colleagues (2011) reported that strategic memory training increased brain activation in regions involved in memory encoding before training and induced new activations in regions that were not active prior to training in individuals with MCI. Interestingly, the differences between memory encoding-related brain patterns in MCI compared to healthy older controls were attenuated after training, suggesting that some restoration took place. Furthermore, the performance improvement was correlated with a newly activated region, the right parietal area, which was normalised in MCI. These results suggest that strategic cognitive training facilitates the recruitment of an intact alternative network to compensate the impaired primary network but can also contribute to meaningful restoration. Hampstead et al. (2012) found increased activation almost exclusively in specialised regions after associative memory training in MCI individuals. They reported increased activation during both encoding and retrieval in hippocampal regions that were less activated compared to healthy older controls before training. These results show that associative memory training has a restorative effect on the primary network. Similarly, Forster et al. (2011) showed that a multimodal intervention reduced decline in brain glucose metabolism in MCI and early AD, suggesting that it had an effect on neuronal injury.

Cognitive training was also found to have an effect on the structure of the brain in prodromal AD. Engvig and colleagues (2014) reported increased grey matter volume in regions encompassing the episodic memory network following strategic associative memory training in individuals with SCD. Interestingly, the strongest volume differences were found in the right prefrontal cortex, which is activated during contextual monitoring and episodic retrieval. Thus, compensatory mechanisms may mediate training-related structural adaptation. Despite no significant hippocampal volume changes, there was a significant correlation between volume change and post-training memory improvement suggesting that individual differences may modulate the extent of the structural hippocampal restoration in SCD individuals. No study has looked at the effect of cognitive training on beta-amyloid (βA) deposits, which is one of the main neuropathologies associated with AD. Showing that cognitive training reduces βA deposition would be of tremendous consequences and may not be that far-fetched, as observational studies have reported that a cognitively stimulating lifestyle is associated with lower levels of βA deposits in older adults (Landau et al. 2012).

The Contribution of Brain Imaging to Models of Training

Models of training-induced brain changes have been proposed to interpret the effect of cognitive training on the brain. According to the CRUNCH model (Reuter-Lorenz and Cappell 2008), compensation in older adults is supported by both increased activation of specialised brain regions and strategic recruitment of alternative regions. In turn, Lövdén and colleagues (2010) argue that plastic changes occur when there is a mismatch between environmental demands and the capacity of the system processes, which should result in structural brain changes with functional impact. The STAC-r model proposes that individual differences in life-course events can modify neural resources and compensatory capacities (Reuter-Lorenz and Park 2014). The INTERACTIVE model (Belleville et al. 2014) proposes that characteristics of subjects (E.g. cognitive reserve, severity of the disease) and training modalities (E.g. format, target) modulate the type of neural changes induced by cognitive training. Studies reporting training-induced brain changes show that the regions modified by training generally reflect the purported active ingredient of the intervention. Cognitive training that is strategic and that targets preserved cognitive capacities in MCI increases activation in preserved brain regions, which is indicative of compensation. In contrast, cognitive training approaches that rely on adaptive learning or repeated practice are more likely to reduce activation in specialised regions. Additionally, a range of individual factors, the genetic potential for brain plasticity, and educational background may facilitate reliance on alternative networks or structural remodelling. The location and severity of structural impairment in brain-damaged individuals may also influence the success of a compensatory vs. a restorative approach, as restoration may be impossible when structural damage is too severe, for example.

Conclusion and Future Directions

Whether cognitive training and stimulation provided later in life can be used as protective tools against cognitive decline is a major research question. Observational studies have shown an effect of early-life (education) and whole-life (profession, hobbies) cognitive stimulation on age-related cognitive decline, AD and dementia. Compensatory neuroplasticity processes are particularly active during the silent phase of AD (Clement and Belleville 2010) and could be increased to postpone the cognitive decline that leads to the more severe symptoms that define dementia. Although many studies have revealed encouraging findings when using cognitive and brain markers, researchers and clinicians still need to address numerous important questions. First, we need to gain a better understanding of the critical period during which training or stimulation should be provided. The pathological cascade leading to AD, which probably starts many years prior to the diagnosis of dementia, suggests that these programmes are likely to have their highest effect when provided early during the MCI phase or perhaps prior to that stage. However, demonstrating that early training has a long-lasting effect will certainly be very challenging if the outcome is clinical, and there will therefore be a need to adapt the method to those challenges. Additionally, it will be critical to document the effect of individual differences on cognitive training efficacy (see also Katz et al. this volume). For instance, younger age and higher level of education were associated with larger training gain when individuals with MCI were trained with a strategic memory training programme (Belleville et al. 2006). One other critical question is whether the brain processes promoted in late-life cognitive training are the same as those that underlie differences in cognitive reserve or cognitive resilience. The findings that training increases brain activation in alternative compensatory brain networks are consistent with the notion that cognitive reserve reflects more flexible brain networks. Finally, one other major issue that needs to be addressed is the notion of transfer, as cognitive training is intended to have an effect beyond the laboratory or task that is being trained. It appears that older adults may be less prone to generalise learned strategies than younger adults, and whether MCI poses limits to the generalisation of learning is an important question that will need to be resolved.

Acknowledgements S.B. is supported by the Canadian Institute for Health Research, the Natural Sciences and Engineering Research Council of Canada and the Fonds de Recherche du Québec Santé. B.B. receives a postdoctoral fellowship from the Fondation de la famille Lemaire and Fondation Institut de Gériatrie de Montréal. L.P. receives a doctoral fellowship from the Spanish Ministry of Economy and Competitiveness. We would like to thank Christel Cornelis and Gabrielle Ciquier for editorial assistance.

References

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., et al. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*(3), 270–279.

Barnes, D. E., & Yaffe, K. (2011). The projected effect of risk factor reduction on Alzheimer's disease prevalence. *The Lancet Neurology, 10*(9), 819–828.

Belleville, S., Clement, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*(Pt 6), 1623–1634.

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Menard, E., & Gauthier, S. (2006). Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: evidence from a cognitive intervention program. *Dementia and Geriatric Cognitive Disorders, 22*(5–6), 486–499.

Belleville, S., Mellah, S., de Boysson, C., Demonet, J. F., & Bier, B. (2014). The pattern and loci of training-induced brain changes in healthy older adults are predicted by the nature of the intervention. *PLoS One, 9*(8), e102710.

Belleville, S., Ménard, M. C., de Boysson, C., & Sylvain-Roy, S. (2008). Characterizing memory deficits in mild cognitive impairment. In W. Sossin, J. C. Lacaille, V. Castellucci, & S. Belleville (Eds.), *Progress in brain research, essence of memory* (pp. 365–375). Elsevier: Amsterdam.

Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age (Dordrecht, Netherlands), 36*(4), 9688.

Carlson, M. C., Saczynski, J. S., Rebok, G. W., Seeman, T., Glass, T. A., McGill, S., et al. (2008). Exploring the effects of an "everyday" activity program on executive function and memory in older adults: Experience Corps. *The Gerontologist, 48*(6), 793–801.

Clement, F., & Belleville, S. (2010). Compensation and disease severity on the memory-related activations in mild cognitive impairment. *Biological Psychiatry, 68*(10), 894–902.

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Dale, A. M., Holland, D., et al. (2014). Effects of cognitive training on gray matter volumes in memory clinic patients with subjective memory impairment. *Journal of Alzheimer's Disease, 41*(3), 779–791.

Forster, S., Buschert, V. C., Teipel, S. J., Friese, U., Buchholz, H. G., Drzezga, A., et al. (2011). Effects of a 6-month cognitive intervention on brain metabolism in patients with amnestic MCI and mild Alzheimer's disease. *Journal of Alzheimer's Disease, 26*(Suppl 3), 337–348.

Gagnon, L. G., & Belleville, S. (2011). Working memory in mild cognitive impairment and Alzheimer's disease: Contribution of forgetting and predictive value of complex span tasks. *Neuropsychology, 25*(2), 226–236.

Gagnon, L. G., & Belleville, S. (2012). Training of attentional control in mild cognitive impairment with executive deficits: Results from a double-blind randomised controlled study. *Neuropsychological Rehabilitation, 22*(6), 809–835.

Gaitán, A., Garolera, M., Cerulla, N., Chico, G., Rodriguez-Querol, M., & Canela-Soler, J. (2013). Efficacy of an adjunctive computer-based cognitive training program in amnestic mild cognitive impairment and Alzheimer's disease: A single-blind, randomized clinical trial. *International Journal of Geriatric Psychiatry, 28*(1), 91–99.

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Giddens, M., & Sathian, K. (2012). Mnemonic strategy training partially restores hippocampal activity in patients with mild cognitive impairment. *Hippocampus, 22*(8), 1652–1658.

Herrera, C., Chambon, C., Michel, B. F., Paban, V., & Alescio-Lautier, B. (2012). Positive effects of computer-based cognitive training in adults with mild cognitive impairment. *Neuropsychologia, 50*(8), 1871–1881.

Kinsella, G. J., Mullaly, E., Rand, E., Ong, B., Burton, C., Price, S., et al. (2009). Early intervention for mild cognitive impairment: A randomised controlled trial. *Journal of Neurology, Neurosurgery, and Psychiatry, 80*(7), 730–736.

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50–76.

Landau, S. M., Marks, S. M., Mormino, E. C., Rabinovici, G. D., Oh, H., O'Neil, J. P., et al. (2012). Association of lifetime cognitive engagement and low beta-amyloid deposition. *Archives of Neurology, 69*(5), 623–629.

Lee, H., Voss, M. W., Prakash, R. S., Boot, W. R., Vo, L. T., Basak, C., et al. (2012). Videogame training strategy-induced change in brain function during a complex visuomotor task. *Behavioural Brain Research, 232*(2), 348–357.

Lövdén, M., Bodammer, N. C., Kuhn, S., Kaufmann, J., Schutze, H., Tempelmann, C., et al. (2010). Experience-dependent plasticity of white-matter microstructure extends into old age. *Neuropsychologia, 48*(13), 3878–3883.

Man, D. W., Chung, J. C., & Lee, G. Y. (2012). Evaluation of a virtual reality-based memory training programme for Hong Kong Chinese older adults with questionable dementia: A pilot study. *International Journal of Geriatric Psychiatry, 27*(5), 513–520.

Olchik, M. R., Farina, J., Steibel, N., Teixeira, A. R., & Yassuda, M. S. (2013). Memory training (MT) in mild cognitive impairment (MCI) generates change in cognitive performance. *Archives of Gerontology and Geriatrics, 56*(3), 442–447.

Park, D. C., Lodi-Smith, J., Drew, L., Haber, S., Hebrank, A., Bischof, G. N., et al. (2014). The impact of sustained engagement on cognitive function in older adults The Synapse Project. *Psychological Science, 25*(1), 103–112.

Petersen, R. C., Thomas, R. G., Grundman, M., Bennett, D., Doody, R., Ferris, S., et al. (2005). Vitamin E and donepezil for the treatment of mild cognitive impairment. *The New England Journal of Medicine, 352*(23), 2379–2388.

Rapp, S., Brenes, G., & Marsh, A. P. (2002). Memory enhancement training for older adults with mild cognitive impairment: A preliminary study. *Aging & Mental Health, 6*(1), 5–11.

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science, 17*(3), 177–182.

Reuter-Lorenz, P. A., & Park, D. C. (2014). How does it STAC up? Revisiting the scaffolding theory of aging and cognition. *Neuropsychology Review, 24*(3), 355–370.

Rozzini, L., Costardi, D., Chilovi, B. V., Franzoni, S., Trabucchi, M., & Padovani, A. (2007). Efficacy of cognitive rehabilitation in patients with mild cognitive impairment treated with cholinesterase inhibitors. *International Journal of Geriatric Psychiatry, 22*(4), 356–360.

Schmitter-Edgecombe, M., & Dyck, D. G. (2014). Cognitive rehabilitation multi-family group intervention for individuals with mild cognitive impairment and their care-partners. *Journal of the International Neuropsychological Society, 20*(9), 897–908.

Strobach, T., Frensch, P., Müller, H., & Schubert, T. (2015). Evidence for the acquisition of dual-task coordination skills in older adults. *Acta Psychologica, 160*, 104–116.

Tappen, R. M., & Hain, D. (2014). The effect of in-home cognitive training on functional performance of individuals with mild cognitive impairment and early-stage Alzheimer's disease. *Research in Gerontological Nursing, 7*(1), 14–24.

Unverzagt, F. W., Kasten, L., Johnson, K. E., Rebok, G. W., Marsiske, M., Koepke, K. M., et al. (2007). Effect of memory impairment on training outcomes in ACTIVE. *Journal of the International Neuropsychological Society, 13*(6), 953–960.

Vidovich, M. R., Lautenschlager, N. T., Flicker, L., Clare, L., McCaul, K., & Almeida, O. P. (2015). The PACE study: A randomized clinical trial of cognitive activity strategy training for older people with mild cognitive impairment. *The American Journal of Geriatric Psychiatry, 23*(4), 360–372.

Voss, M. W., Prakash, R. S., Erickson, K. I., Boot, W. R., Basak, C., Neider, M. B., et al. (2012). Effects of training strategies implemented in a complex videogame on functional connectivity of attentional networks. *NeuroImage, 59*(1), 138–148.

Part VI
Outlook

The Future of Cognitive Training

Lorenza S. Colzato and Bernhard Hommel

Introduction

This chapter concludes the broad overview of cognitive training activities that this book aims to provide. Where will these activities lead us? What are the upcoming challenges? It is these future-directed questions that we would like to address in this final chapter. We will do so by mixing informed guesses about to-be-expected trends, problems, and challenges in the near future, with our wish list of developments that we would like to see without being able to judge how realistic our wishes are at this point. Among other things, we explain why more specific, mechanistic theories will be necessary to guide the development of successful cognitive training programs, how cognitive training might benefit from combining them with other cognitive-enhancement techniques, and how virtual reality and gamification could be used to support the efficiency of cognitive training. We also emphasize the importance of considering individual differences and discuss the societal and ethical implications of enhancement programs.

Need for Theory

There are only few areas where Kurt Lewin's claim that "nothing is as practical as a good theory" does not apply but hardly any to which it applies more than to the area of cognitive training (see also Taatgen this volume). That people get better when they repeat doing the same thing over and over again is an insight that has been with

---

L.S. Colzato (✉) • B. Hommel
Cognitive Psychology Unit, Leiden Institute for Brain and Cognition,
Leiden University, Leiden, The Netherlands
e-mail: colzato@fsw.leidenuniv.nl; hommel@fsw.leidenuniv.nl

T. Strobach, J. Karbach (eds.), *Cognitive Training*,
DOI 10.1007/978-3-319-42662-4_19

academic psychology for more than 150 years. And yet, we still see many approaches to cognitive training that do not seem to go much beyond this general insight. The typical punishment for such theoretically parsimonious approaches is the lack of any interesting transfer from the actually trained cognitive ability to any other cognitive task or skill, which should not be surprising. To reach interesting levels of transfer requires rather good ideas about the mechanisms underlying the cognitive functions one aims to improve. But we still do not see too many of them.

For instance, theorizing about cognitive control—a particularly important cognitive function worth enhancing in many subpopulations—still does not go beyond distinguishing some general, vaguely described factors (like updating, shifting, and inhibition: Miyake et al. 2000) and related brain areas, while specific models about what these factors and areas are really doing and exactly how they operate are lacking. Consider task switching, which plays an important role in many training programs. How exactly do people switch from one task to another? What do we really know about this process and the cognitive codes it operates on, after it has been addressed in hundreds and hundreds of studies? What exactly is a task set? How is it generated from instructions? Can they become stored and retrieved? As long as we have no interesting, mechanistically detailed answers to questions of that sort, it is difficult to see how training programs can generate far transfer in systematic, generalizable ways. Generating more interesting answers is likely to require more collaboration between researchers with more theoretical and researchers with more practical skills and interests. Creating such collaborations will require flexible funding schemes and substantial resources.

Enhancing Cognitive Training

From a more practical perspective, it would seem promising to combine methods suitable for cognitive enhancement. Indeed, there is preliminary evidence that cognitive training programs can be successfully enhanced by boosting performance outcomes in various ways.

First, there is increasing evidence that cognitive training may benefit from the combination with pharmacological interventions. In particular, interventions acting on the dopaminergic system seem ideal to enhance learning in cognitive training given the role of dopamine in associative learning (Schultz et al. 1997) and executive functioning (Colzato et al. 2010, 2014). Indeed, the combined administration of L-Dopa and D-amphetamine has been found to boost language learning in healthy humans (Breitenstein et al. 2004; Knecht et al. 2004). More recently, Gilleen and colleagues (2014) sought to enhance performance on cognitive tasks (working memory [WM], verbal learning, and learning a new language) in healthy participants by combining cognitive training with the cognitive-enhancing drug modafinil. While memory and verbal learning was unaffected, new-language learning was significantly enhanced through the combination, which is at least encouraging.

Second, there is some evidence that cognitive training benefits from the combination with brain stimulation by means of *transcranial direct current stimulation* (tDCS). tDCS is a noninvasive brain stimulation technique that involves passing a constant direct electrical current through the cerebral cortex (via electrodes placed upon the scalp) flowing from the positively charged anode to the negatively charged cathode (Nitsche and Paulus 2011). This technique has developed into a promising tool to boost human cognition (Kuo and Nitsche 2012). Very recently, Richmond and colleagues (2014) suggested that tDCS might support WM training. Participants engaged in an adaptive WM training regime for 10 sessions, concurrent with either active or sham stimulation of dorsolateral prefrontal cortex. Before and after training, a battery of tests tapping domains known to relate to WM abilities was administered. tDCS was shown to enhance learning in the verbal part of the cognitive training and to enhance near transfer to other untrained WM tasks. We emphasize that this study did not include a follow-up session and needs to be replicated and generalized to other cognitive domains. And yet, it does provide preliminary evidence that tDCS might enhance cognitive training and support far transfer.

Third, a number of findings suggest that cognitive training may benefit from a combination with neurofeedback. Neurofeedback is a technique that teaches participants to control their own brain activity by providing systematic feedback about internal states (Sherlin et al. 2011), such as neural oscillations and slow cortical potentials assessed by means of electroencephalography (EEG; Birbaumer et al. 2009). The modulation of neural oscillations through EEG neurofeedback has been shown to enhance different cognitive functions as a function of the frequencies of neural activity (see Gruzelier 2014 for a recent review). For instance, upregulating the upper alpha band improves mental rotation (e.g., Hanslmayr et al. 2005; Zoefel et al. 2011), upregulating gamma-band activity enhances episodic retrieval (Keizer et al. 2010), and upregulating the mu-rhythm supports declarative learning (Hoedlmoser et al. 2008). Very recently, Enriquez-Geppert and colleagues (2014) have investigated the modulation of frontal-midline theta oscillations by neurofeedback and its putative role for executive functioning. Before beginning and after completing an individualized, eight-session gap-spaced intervention, tasks tapping executive functions were administered while measuring the EEG. Compared to a pseudo-neurofeedback group, the group receiving active neurofeedback training showed better performance in WM updating and cognitive flexibility. The idea that learning to increase frontal-midline theta amplitudes facilitates executive functions is captivating and opens the possibility to use neurofeedback to boost the efficiency of cognitive training.

Fourth, research on human-machine interfaces increasingly points to an interesting role of haptic feedback, as provided by means of somatosensory information (vibration) delivered through a user interface. Training with haptic feedback has been found to reliably support the acquisition of knowledge in chemistry (Bivall et al. 2011) and physics (Han and Black 2011), as well as object manipulation (Stepp et al. 2012). Even though it is not yet clear whether such learning improvements transfer to other tasks, the incorporation of haptic feedback in cognitive training programs represents an interesting avenue for the future.

These are just a few examples for how cognitive training techniques can be enhanced by techniques that have been shown to support learning, but progress in technology is likely to generate more and more options in the near future. While many of them are interesting indeed, their novelty brings a number of risks with it. For instance, new developments have made it possible to produce tDCS-based tools for the use in daily life. While that provides interesting opportunities for research (e.g., in freeing participants from daily visits in the lab), official tests and guidelines for the safe personal use of such devices are lacking. As pointed out by Jwa (2015), given that tDCS is currently not covered by the existing regulatory framework, there are potential risks of misusing this device, in particular as its long-term effects on the brain have not been fully investigated and understood. A recent initiative supported by several research institutes and scientists calls for a more critical and active role of the scientific community in evaluating the sometimes far-reaching, sweeping claims from the brain training industry with regard to the impact of their products on cognitive performance (Max Planck Institute on Human Development, Stanford Center on Longevity 2014).

Recently, colleagues and us (Steenbergen et al. 2015) have taken this recommendation to heart and tested whether and to what degree the commercial tDCS headset *foc.us* improves cognitive performance, as advertised in the media. We used a single-blind, sham-controlled, within-subject design to investigate the effect of online and off-line *foc.us* tDCS—applied over the prefrontal cortex in healthy young volunteers—on WM updating. In contrast to the previous positive findings with CE-certified laboratory tDCS, active stimulation with foc.us led to a significant *decrease* in WM updating. This observation reinforces the view that the scientific community can, and presumably should, play a crucial role in helping to create regulations and official guidelines for the future incorporation of cognitive and neuro-technologies in cognitive training.

Virtual and Augmented Reality

The use of virtual and augmented reality (VAR) has become popular in several areas of cognitive and clinical psychology, where it, for instance, is used to treat phobia (Juan et al. 2005). These kinds of uses could also be seen as enhancing techniques, similar to those discussed in the previous section. Indeed, VAR techniques can serve to visualize instructions and provide more realistic feedback about the achievements of trainees. However, we think that VAR techniques are particularly well suited to address an aspect of cognitive training that has remained underdeveloped so far: the possibility of embodied cognition. The embodied-cognition approach is not particularly homogeneous and theoretically straightforward (for a discussion, see Wilson 2002), but the general idea is that cognition emerges from concrete sensorimotor interactions with one's environment, which assigns an important role to one's body. This fits with older ideomotor considerations about the emergence of cognition through action (Hommel 2015), which, for instance, have motivated the development of the theory of event coding (Hommel et al. 2001). It remains to be seen whether, and in which sense, the idea of embodiment increases our insight into basic cognitive functions and control processes, but if it does, we will need more realistic experimental designs and training conditions. For these purposes, VAR seems ideal.

For instance, cognitive aging is not unlikely to be associated, if not facilitated, by motivational decline that is produced by changes in self-perception. As elaborated elsewhere (Hommel and Kibele 2016), the retired elderly is likely to perceive herself as someone who is no longer productive. Given that most jobs allow people to exert impact on the real world, this impression is based on a real fact—retirement does mean losing this impact. To the degree that the outcome of self-perception affects motivation, this would be likely to undermine the motivation of the retired individual. This in turn would make it difficult both to maintain one's cognitive abilities and to compensate for age-related cognitive decline by means of training. VAR could help to prevent and counteract vicious cycles of this sort by turning the self-perception into a more active one.

Gamification

The widespread popularity of smartphones has led to a real explosion of "apps" to enhance cognitive functioning, ranging from simple alerts reminding the elderly to take her pill to theoretically guided programs to systematically improve specific cognitive functions, such as spatial imagination. Industry and funding agencies have taken notice of the many opportunities these techniques can open, and the current European research agenda (Horizon 2020) has various calls to promote gamification. Obviously, this is likely to strengthen this trend further in the near future, but we think that the full potential of gamification is not always appreciated. Turning psychological experiments and training procedures into apps is certainly handy for both researchers and users, especially as it allows to integrate training programs better with real-life circumstances. Even more importantly, however, gamification will make cognitive training programs more acceptable and increase the motivation to get through with them. Laboratory work on the impact of cognitive training is typically based on data collected from paid or otherwise compensated participants, which reduces the risk of dropout even with extensive training and not-so-exciting tasks. To make it to real-life circumstances, however, the format of cognitive training will need to change dramatically, so to convince individuals to participate. Like physical exercise, it can take a while before cognitive training produces benefits that are recognizable for the trainee. Continuous, fine-graded feedback helps to overcome that problem but only if improvements are visible enough to keep the trainee motivated. Especially training with more preventive aims, for which immediate benefits may not be visible at all, motivation remains an issue. Gamification can help to tackle that issue by making the process more fun and providing additional, benefit-independent reward.

Individual Tailoring

Most cognitive training programs have a one-size-fits-all design and assume that everyone benefits from the intervention more or less the same way and to more or less the same degree (see also Katz et al. this volume). There are several reasons suggesting that this is unlikely to be true. In fact, we suggest that the efficiency of cognitive training and the successful transfer to untrained tasks will often be modulated by interindividual differences, including pre-existing neurodevelopmental factors and differences with a genetic basis. Accordingly, only training programs that are tailored to individual abilities, skills, and needs are likely to succeed.

In particular, we believe that substantial parts of the current controversy about the benefit of the regular use of cognitive training are due to the failure to consider individual differences. For instance, while Schmiedek and colleagues (2010) found positive transfer of cognitive training both in young and older adults, Owen and colleagues (2010) famously reported about a failure to find transfer in 11,430 participants trained online over a period of six weeks. The participants of Owen et al. were trained on cognitive tasks developed to improve reasoning, memory, planning, visuospatial skills, and attention. Participants improved in every single task, as one would expect, but the benefit did not generalize to any untrained tasks. The authors conclude that this provides "no evidence to support the widely held belief that the regular use of computerized brain trainers improves general cognitive functioning in healthy participants beyond those tasks that are actually being trained" (Owen et al. 2010, p. 777).

While we do not question the importance of such large-scale studies, we consider arguments based on mean findings in not further differentiated populations problematic, especially if individual improvements are not taken into account as well. The reason why this is important is that the functions relating psychological functions (and/or their neural underpinnings) to performance are often not linear. For instance, brainstorming-like creativity is assumed to rely on mood and on (presumably striatal) dopamine, but there is evidence that a medium (i.e., not the highest) dopamine level produces the best performance (Akbari Chermahini and Hommel 2010). Given the evidence that inducing positive mood increases the dopamine level, this suggests that individuals with a low dopamine level get better, while those with a medium dopamine level do not or even get worse—which is indeed what has been observed (Akbari Chermahini and Hommel 2012).

Along the same lines, we also considered that successful transfer of game-based cognitive improvements to untrained tasks might be modulated by the genetic variability related to the catechol-O-methyltransferase (COMT)—an enzyme responsible for the degradation of dopamine (Colzato et al. 2014). Participants were genotyped for the COMT Val^{158}Met polymorphism and trained on playing "Half-Life 2," a first-person shooter game that has been shown to improve cognitive flexibility. Pre-training (baseline) and post-training measures of cognitive flexibility were acquired by means of a task-switching paradigm. As predicted, Val/Val homozygous individuals (i.e., individuals with a beneficial genetic predisposition for cognitive flexibility) showed larger beneficial transfer effects than Met/-carriers, supporting the possibility that genetic predisposition modulates transfer effects and that cognitive training promotes cognitive flexibility in individuals with a suitable genetic predisposition. Even if this study needs to be replicated with a larger sample size, we view it as proof-of-principle that highlights the importance of considering individual differences. Considering these differences and assessing how they interact with different training regimes will allow for the development of personalized, individually tailored training programs. Not only will these programs be more effective but they also will be much more motivating for participants (as unnecessary failures due to person-method mismatches can be avoided) and more cost-efficient. This in turn will make the implementation of such programs more likely even in times of sparse budgets. In view of the rapid aging of European societies, the number of potential beneficiaries of such an individualized approach is dramatically increasing, and the societal need for maximizing the human cognitive potential in the elderly will grow further as the economic situation will require extensions of the working lifetime.

Societal Context

Research on, and the application of, cognitive training depends on the societal context, which affects the respective funding budgets and acceptability. Accordingly, it is important to consider which direction societal developments related to these issues are taking. Economically, the interest in cognitive training is mainly driven by the increasing costs of the welfare system, especially with regard to the increasing age of citizens in Western societies. Cognitive training can help, so one version of the idea, to delay cognitive decline in the elderly, which would extend the time people can live autonomously and, thus, reduce the welfare costs for the time thereafter. Along the same lines, training children could speed up the education of healthy individuals and reduce the risk of behavioral deviance and pathology, again with considerable savings for welfare and education systems. But there is also a more ideological reason for the increased interest in cognitive training. Both Eastern and Western societies are continuously driven toward more individualism, which emphasizes the existence and often also the importance of individual differences over commonalities and collectivistic values. These tendencies go hand in hand with ideological developments in public opinion and within political parties, which in many countries have gravitated toward more neoliberal, individualism-heavy positions over the last 15 years or so. Among other things, this has involved a rather systematic deconstruction of the welfare system and established the view of the individual as an architect of his or her own life.

Research on cognitive training has benefited from both aspects of this trend. The economic problems of the welfare system have boosted the interest in procedures and activities that make welfare societally more affordable, and the ideological turn toward individualism provides a natural breeding ground for the public interest in procedures and activities that help to express and to further develop individual needs and interests. We do not expect that the economic problems will disappear soon, but it is possible that the ideological development leads to a swing back. To the degree that it will, the opposition and ethical objections to cognitive training programs may increase substantially.

Ethical Challenges

Like any psychological intervention, cognitive training raises all sorts of ethical issues (Bostrom and Sandberg 2009). In the following, we would like to emphasize two of them, as we suspect that they are likely to dominate future discussions. The first issue has to do with the "naturalness" of the intervention. Encouraging people to take considerable active efforts to change their mind and brain, as we would hope for effective training, must be considered unnatural, in the sense that it is likely to create a situation that without these efforts would not exist. While this is the very point of any sort of training, some people take issue with that. For instance, it has been considered that methods of cognitive enhancement may disrespect dignity and human nature, augment inauthenticity and cheating behavior, and may encourage an uncontrolled striving for excellence and perfection (Habermas 2003; Kass 2002). Such considerations are not far-fetched, as witnessed by the increasing use of cognitive-enhancing drugs, such as modafinil and Ritalin, by students to boost their academic performance. Soon, universities may opt to prohibit drug use altogether or to tolerate it in some situations (exams). The same reasoning is also applicable to commercial brain stimulation devices, which are available on the Internet without any restrictions.

The second, somewhat related issue is that the availability of cognitive training techniques creates, or at least increases, a tension between two widely shared ethical principles: individual freedom and equality. While effective cognitive training programs can be taken to support the expression of the former (assuming that the "unnaturalness" objection can be overcome), it may conflict with the latter. Societies and upward mobility in particular rely increasingly on competition, which emphasizes individual performance and abilities. Cognitive training is likely to create "positional benefits" by improving one's social and economic status as compared to others. While this may be considered an acceptable individual choice, it may have repercussions for general public expectations and criteria. Once a number of individuals have demonstrated that it is possible to improve one's cognitive abilities, public pressure on other individuals could arise to improve their abilities as well. The existence of effective cognitive training programs could thus create or increase the pressure of always being "at the top," to work harder, longer, and more intensively, which in the end may exacerbate the problems one was intending to solve. In other words, the mere possibility to enhance one's cognitive abilities could increase social competition. Worse, as the probability to benefit from cognitive training may differ between individuals, the availability of training programs may contribute to the emergence and increase the size of societal gaps (cf. Bostrom and Sandberg 2009).

Counterarguments exist for both of these ethical issues. For one, any kind of psychological intervention and any kind of training must be considered equally unnatural as cognitive training. Accordingly, if one finds psychologically guided education and physical exercises of athletes acceptable, it is difficult to see in which sense cognitive training falls into an ethically different category. For instance, while objections to cognitive enhancement by means of particular diets or food supplements (Colzato et al. 2013) have not been put forward so far, the impact of cognitive-enhancing drugs and neuro-technologies, such as tDCS and neurofeedback, rests basically on the same cognitive and neural mechanisms. Obviously, this raises the question why social acceptance might be more widespread for the former than for the latter.

For another, cognitive training could well be used as a way of reducing, rather than increasing, societal/social inequalities by allowing all, and not just the economically privileged individuals, to fully explore and exploit their cognitive potential. This would not eliminate competition but create more equal terms (Savulescu 2009). Moreover, it is important to consider that the widespread use of cognitive training and the associated cognitive benefits might have rather dramatic social benefits. Indeed, some studies estimate that augmenting the average IQ of the world population by no more than 3 % would reduce poverty rates by 25 % (Schwartz 1994) and result in an annual economic gain of US$ 165–195 billion and 1.2–1.5 % GDP (Salkever 1995).

Conclusion

Taken altogether, the future of cognitive training will heavily depend on theoretical, technological, and societal developments. For some of these developments, cognitive researchers are solely responsible, while they can only contribute to others. As we have tried to emphasize, cognitive training is not just one more psychological intervention, but it touches important societal and ethical issues. Accordingly, it would be wise if researchers actively engaged in public discussion of these issues to bring in the necessary expertise, so as to make sure that both risks and promises of cognitive training are realistically assessed.

References

Akbari Chermahini, S., & Hommel, B. (2010). The (b)link between creativity and dopamine: Spontaneous eye blink rates predict and dissociate divergent and convergent thinking. *Cognition, 115*, 458–465.

Akbari Chermahini, S., & Hommel, B. (2012). More creative through positive mood? Not everyone! *Frontiers in Human Neuroscience, 6*, 319.

Birbaumer, N., Ramos Murguialday, A., Weber, C., & Montoya, P. (2009). Neurofeedback and brain-computer interface clinical applications. *International Review of Neurobiology, 86*, 107–117.

Bivall, P., Ainsworth, S., & Tibell, L. A. (2011). Do haptic representations help complex molecular learning? Science Education, 95, 700-719. doi: 10.1002/sce.20439.

Bostrom, N., & Sandberg, A. (2009). Cognitive enhancement: Methods, ethics, regulatory challenges. *Science and Engineering Ethics, 15*(3), 311–341.

Breitenstein, C., Wailke, S., Bushuven, S., Kamping, S., Zwitserlood, P., Ringelstein, E. B., et al. (2004). D-amphetamine boosts language learning independent of its cardiovascular and motor arousing effects. *Neuropsychopharmacology, 29*, 1704–1714.

Colzato, L. S., Jongkees, B., Sellaro, R., & Hommel, B. (2013). Working memory reloaded: Tyrosine repletes updating in the N-Back task. *Frontiers in Behavioral Neuroscience, 7*, 700.

Colzato, L. S., van den Wildenberg, W., & Hommel, B. (2014). Cognitive control and the COMT Val158Met polymorphism: Genetic modulation of videogame training and transfer to task-switching efficiency. *Psychological Research, 78*, 670–678.

Colzato, L. S., Waszak, F., Nieuwenhuis, S., Posthuma, D., & Hommel, B. (2010). The flexible mind is associated with the Catechol-O-methyltransferase (COMT) Val158Met polymorphism: Evidence for a role of dopamine in the control of task switching. *Neuropsychologia, 48*, 2764–2768.

Enriquez-Geppert, S., Huster, R. J., Figge, C., & Herrmann, C. S. (2014). Self-regulation of frontal-midline theta facilitates memory updating and mental set shifting. *Frontiers in Behavioral Neuroscience, 8*, 420.

Gilleen, J., Michalopoulou, P. G., Reichenberg, A., Drake, R., Wykes, T., Lewis, S. W., et al. (2014). Modafinil combined with cognitive training is associated with improved learning in healthy volunteers—A randomised controlled trial. *European Neuropsychopharmacology, 24*(4), 529–539.

Gruzelier, J. H. (2014). EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. *Neuroscience & Biobehavioral Reviews, 44*, 124–141.

Habermas, J. (2003). *The future of human nature*. Cambridge: Polity Press.

Han, I., & Black, J. B. (2011). Incorporating haptic feedback in simulation for learning physics. *Computers & Education, 57*(4), 2281–2290.

Hanslmayr, S., Sauseng, P., Doppelmayr, M., Schabus, M., & Klimesch, W. (2005). Increasing individual upper alpha power by neurofeedback improves cognitive performance in human subjects. *Applied Psychophysiology and Biofeedback, 30*(1), 1–10.

Hoedlmoser, K., Pecherstorfer, T., Gruber, G., Anderer, P., Doppelmayr, M., Klimesch, W., et al. (2008). Instrumental conditioning of human sensorimotor rhythm (12–15 Hz) and its impact on sleep as well as declarative learning. *Sleep, 31*(10), 1401.

Hommel, B. (2015). The theory of event coding (TEC) as embodied-cognition framework. *Frontiers in Psychology, 6*, 1318.

Hommel, B., & Kibele, A. (submitted for publication). Down with retirement: Implications of embodied cognition for healthy aging.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849–878.

Max Planck Institute on Human Development, Stanford Center on Longevity. (2014). *A consensus on the brain training industry from the scientific community*. Retrieved March 2, 2015.

Juan, M. C., Alcaniz, M., Monserrat, C., Botella, C., Banos, R. M., & Guerrero, B. (2005). Using augmented reality to treat phobias. *IEEE Computer Graphics and Applications, 25*(6), 31–37.

Jwa, A. (2015). Early adopters of the magical thinking cap: A study on do-it-yourself (DIY) transcranial direct current stimulation (tDCS) user community. *Journal of Law and Biosciences.* doi:10.1093/jlb/lsv017.

Kass, L. (2002). *Life, liberty, and defense of dignity: The challenge for bioethics*. San Francisco: Encounter Books.

Keizer, A. W., Verment, R., & Hommel, B. (2010). Enhancing cognitive control through neurofeedback: A role of gamma-band activity in managing episodic retrieval. *NeuroImage, 49*, 3404–3413.

Knecht, S., Breitenstein, C., Bushuven, S., Wailke, S., Kamping, S., Floel, A., Zwitserlood, P., & Ringelstein, E. B. (2004). Levodopa: Faster and better word learning in normal humans. *Annals of Neurology, 56*, 20–26.

Kuo, M. F., & Nitsche, M. A. (2012). Effects of transcranial electrical stimulation on cognition. *Clinical EEG and Neuroscience, 43*, 192–199.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100.

Nitsche, M. A., & Paulus, W. (2011). Transcranial direct current stimulation—Update 2011. *Restorative Neurology and Neuroscience, 29*, 463–492.

Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., et al. (2010). Putting brain training to the test. *Nature, 465*, 775–778.

Richmond, L. L., Wolk, D., Chein, J., & Olson, I. R. (2014). Transcranial direct current stimulation enhances verbal working memory training performance over time and near transfer outcomes. *Journal of Cognitive Neuroscience, 26*(11), 2443–2454. doi:10.1162/jocn_a_00657.

Salkever, D. S. (1995). Updated estimates of earnings benefits from reduced exposure of children to environmental lead. *Environmental Research, 70*, 1–6.

Savulescu, J. (2009). Enhancement and Fairness. In P. Healey (Ed.), *Tomorrow’s people: The challenges of technologies for life-extension and enhancement*. London: Earthscan.

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Neuroscience, 2*, 27. doi:10.3389/fnagi.2010.00027.

Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science, 275*, 1593–1599.

Schwartz, J. (1994). Low-level lead exposure and children’s IQ: A meta-analysis and search for a threshold. *Environmental Research, 65*, 42–55.

Sherlin, L. H., Arns, M., Lubar, J., Heinrich, H., Kerson, C., Strehl, U., et al. (2011). Neurofeedback and basic learning theory: Implications for research and practice. *Journal of Neurotherapy, 15*, 292–304. doi:10.1080/10874208.2011.623089.

Steenbergen, L., Sellaro, R., Hommel, B., Kühn, S., & Colzato, L. S. (2015). “Unfocus” on foc.us: Commercial tDCS headset impairs working memory. *Experimental Brain Research, 234*(3), 637–643.

Stepp, C. E., An, Q., & Matsuoka, Y. (2012). Repeated training with augmentative vibrotactile feedback increases object manipulation performance. *PLoS One, 7*(2), e32743.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Zoefel, B., Huster, R. J., & Herrmann, C. S. (2011). Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance. *NeuroImage, 54*(2), 1427–1431.