Treatment of Working Memory in Autism

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Introduction

Individuals with autism spectrum disorders (ASD) have documented deficits in executive functions (Hill 2004). Executive functions are generally considered the mechanisms and processes that control goal-directed behavior, including planning, attention, inhibition, multitasking, and working memory. Executive functions are not merely of academic interest; they are implicated in virtually all complex activities in which humans engage on a daily basis, including those involved in education, work, social interactions, and independent living skills. Therefore, deficits in executive functions have broad negative implications for independence and general quality of life for individuals with ASD who suffer from them.

Working memory is a particular executive function that has been shown to be impaired in individuals with ASD (Ozonoff et al. 1991). Working memory involves the ability to keep information "online" while engaging in a variety of activities and process it a short time later when a relevant opportunity arises. Working memory is implicated in a large variety of daily tasks with which everyone is faced. For example, a teacher might ask students to "Go to your backpacks, take out yesterday's homework, and find your math worksheet." For students to follow this seemingly simple task, they must remember what they were told to do, walk to their backpacks, be confronted with a variety of distractions, retrieve their homework, walk back to their desks, and then remember what they were initially asked to do – find their math worksheet. The situation can be made more complicated if other distractions happen in the interim, for example, if their backpack was not in the usual location or if they were given some other minor request while looking for their backpack. In other words, in order for students to respond correctly, they must be able to respond to a very large number of stimuli, refrain from getting derailed by

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Table 1 Key publications on treating working memory

Reference	Description	Participants
Hill (2004)	Provides overview of research on executive functions in autism	Individuals with autism
Ozonoff et al. (1991)	Evaluated executive functions, including working memory, in children with autism and typically developing children	Individuals with and without autism
Baltruschat et al. (2011a)	Improved performance on *Counting Span* task using reinforcement; demonstrated maintenance and generalization	Children with autism
Baltruschat et al. (2011b)	Improved performance on *Complex Span* task using reinforcement; demonstrated maintenance and generalization	Children with autism
Baltruschat et al. (2012)	Improved performance on *Digit Span Backwards* task using reinforcement and multiple exemplar training; demonstrated maintenance and generalization	Children with autism

distractions, and all the while retain the original instruction and respond to it later. Maintaining conversations, cooking a meal, and following the simplest instructions at work all involve similar levels of complexity and all require sufficient working memory performance.

Given the ubiquity with which working memory is required for successful daily functioning, the documented deficits in working memory in individuals with ASD raises significant concerns for identifying how these deficits can be remediated. However, the vast majority of research on working memory in individuals with ASD has focused on identifying deficits and differences in functioning compared to other populations (Hill 2004). To date, only three published studies have demonstrated how these deficits can be treated (Baltruschat et al. 2011a, b, 2012) (Table 1). This series of studies evaluates applied behavior analytic methodology for treating working memory deficits in children with autism.

The following is a review of these studies and a discussion of the implications of working memory research for future research on executive functions and clinical interventions for children with autism.

Research Review

Baltruschat and colleagues (2011a) investigated the effectiveness of using behavioral procedures to improve performance on a common test of working memory known as the *Counting Span* task. The *Counting Span* task involves the presentation of a series of flashcards with visual stimuli (i.e., colored shapes) and recalling the correct number of items on each flashcard in the order that they were presented. Three boys with a diagnosis of autism, ages 7, 9, and 11, participated in this study. During baseline, participants were shown 4–5 flashcards with different numbers of ovals and triangles (Fig. 1, left). After seeing each flashcard, the participants were

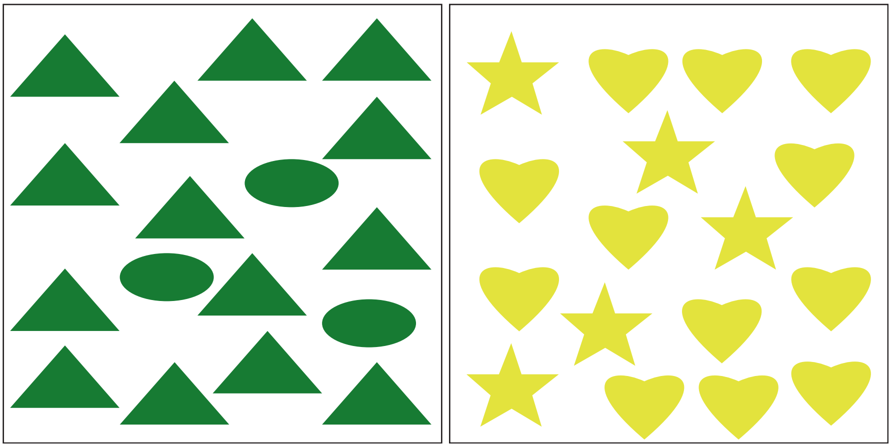

Fig. 1 Sample stimuli from Baltruschat et al. 2011a. Training stimuli (*left*) required participants to count the number of *green ovals*. Generalization stimuli (*right*) required participants to count the number of stimuli that were a different shape (*stars*) and a different color (*yellow*) from those included during training (Reproduced with permission from Elsevier)

asked to report the number of ovals. After seeing the entire set of flashcards (4–5 cards), the participants were asked to recall the number of ovals on each flashcard in the correct order in which the flashcards were presented. This was considered one trial. Participants were not told whether they were correct or incorrect during baseline. Data were collected on the percentage of correct responses per session (Fig. 2). The intervention involved providing each participant with a highly preferred item or activity contingent upon correct responding, i.e., for every correct response the participants received 1 min access to a highly preferred item or activity. Once the participants' accuracy increased substantially and consistently, the maintenance phase was initiated. This phase was identical to baseline, in which the flashcards were presented and no consequences were provided for correct or incorrect responding. Finally, generalization trials were conducted with novel stimuli (Fig. 1, right) not included in training to determine if the treatment generalized or was isolated to stimuli directly reinforced during the intervention phase. The results of this study demonstrated that performance on the *Counting Span* task can be improved by positively reinforcing correct recall on the task across multiple exemplars. Additionally, correct recall generalized across novel stimuli, demonstrating that the effect was not isolated to stimuli directly trained and reinforced. This study was the first to demonstrate that it may be possible to remediate deficits in working memory in children with autism spectrum disorders.

To further analyze the effects of reinforcement on improvements in working memory, Baltruschat and colleagues (2011b) extended their findings from their initial study to another common test of working memory, the *Complex Span* task. The *Complex Span* task is said to measure one's ability to simultaneously process and store information. In this task, the participants are required to recall specific

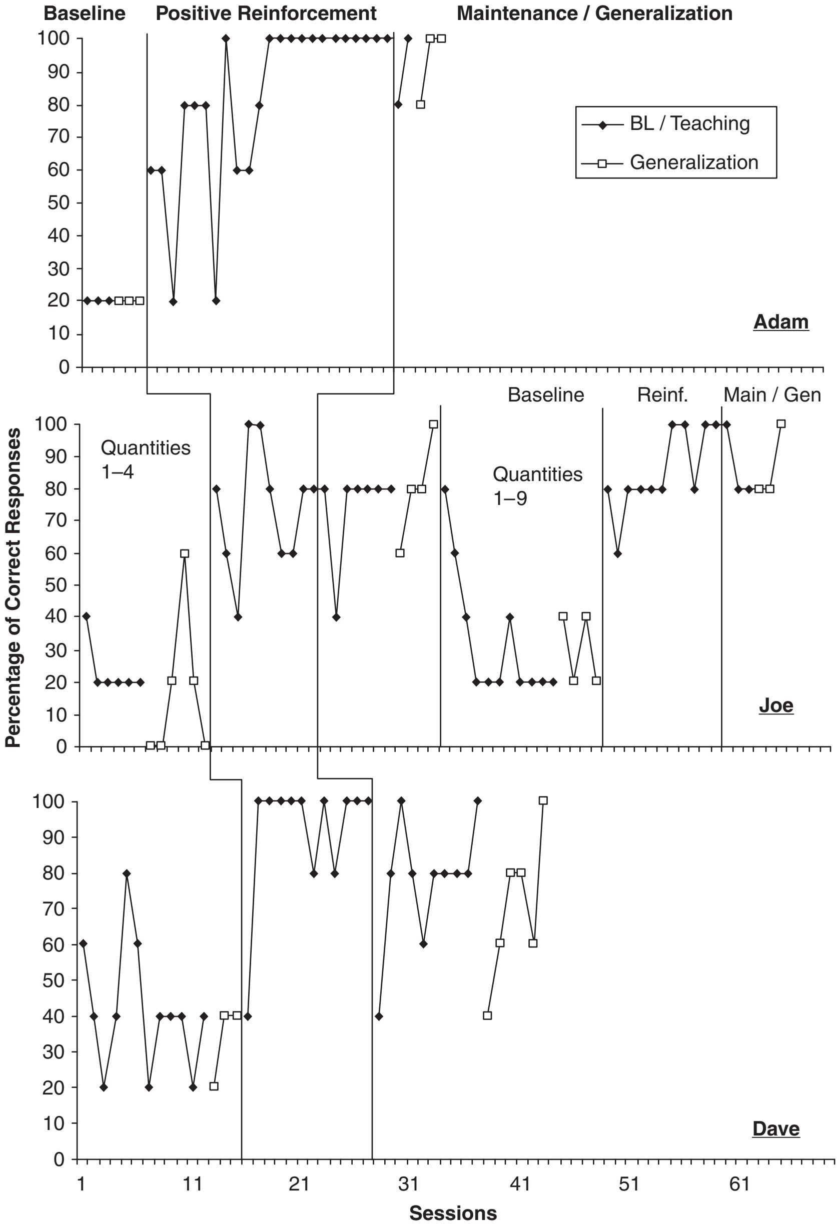

Fig. 2 Working memory performance from Baltruschat et al. 2011a. Percentage of correct responding on working memory tasks for all three participants, during baseline, training, maintenance, and generalization. Training included positive reinforcement. Note that the performance of all three improved with training and the improvement maintained when treatment was removed during maintenance, as well as when untrained tasks were probed in generalization (Reproduced with permission from Elsevier)

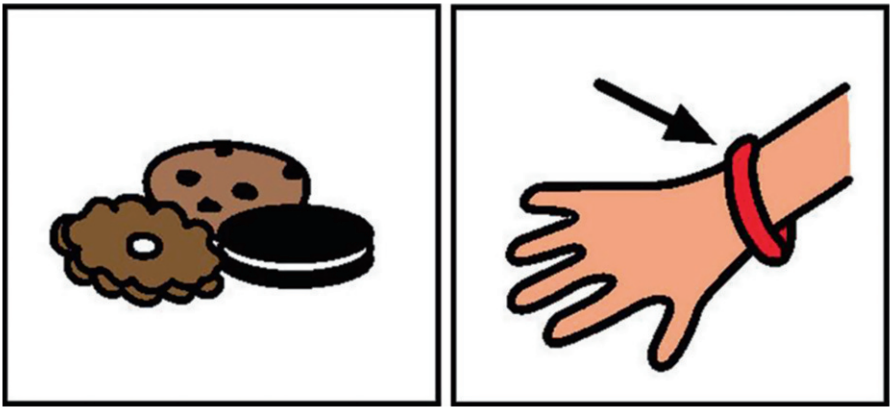

Fig. 3 Sample stimuli from Baltruschat et al. 2011b. Training stimuli (*left*) required participants to identify whether an item could be eaten. Generalization stimuli (*right*) required participants to identify whether an item could be worn as clothing (Reproduced with permission from Elsevier)

information while engaged in another unrelated task. In the study, flashcards were presented with visual stimuli and the participants were asked a question about the function of the stimulus on each card (Fig. 3, left). For example, if presented with a flashcard of a sandwich, the participant was asked "Can you eat it?" After the presentation of all flashcards, the participant was asked to recall the items on the cards in order of presentation. During baseline, no feedback was provided for responding. As in the previous study, the intervention phase involved providing reinforcement for correctly recalling items on flashcards in order of presentation. If positive reinforcement alone did not produce a substantial increase in correct responding, a verbal and/or visual prompt was implemented in addition to reinforcement. The verbal prompt involved vocal rehearsal of the item presented on the flashcard while it was present and then once after its removal prior to presentation of the next flashcard. If responding did not improve, the visual prompt was implemented. During this intervention, each flashcard was visible until the child was asked to recall the items. Two of the three children required the prompting strategies, which were systematically faded prior to post-training sessions. After all training phases were completed, maintenance sessions were conducted and were identical to baseline. In addition, generalization probes were conducted with stimuli that were not included in treatment (Fig. 3, right) and required different classification responses (i.e., "Can you wear it?" instead of "Can you eat it?"). Reinforcement of correct responding on the *Complex Span* task resulted in improvements on trained and untrained stimuli for two of the three participants (Fig. 4). Additional training using the two prompting strategies in addition to positive reinforcement was required for the third participant. These results extended the findings from Baltruschat et al. (2011a) demonstrating that performance on a more complex test of working memory can be improved through behavioral intervention using reinforcement and prompting procedures.

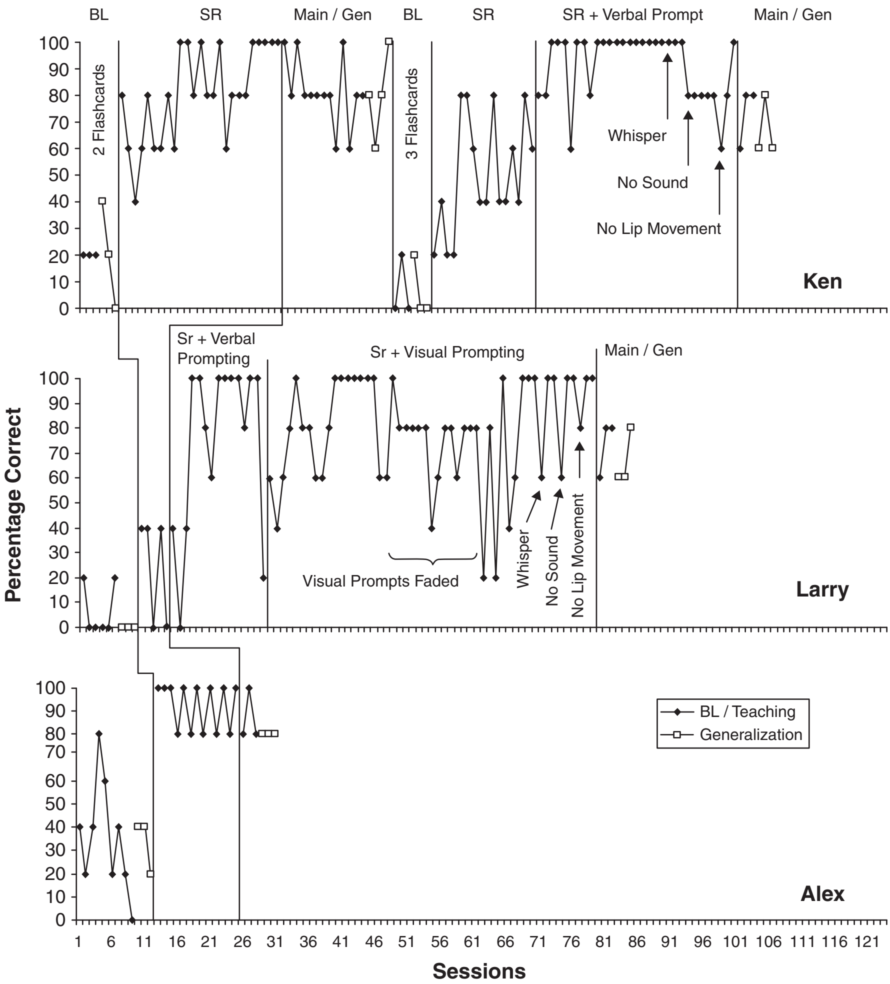

Fig. 4 Working memory performance from Baltruschat et al. 2011b. Percentage of correct responding on working memory tasks for all three participants, during baseline, SR, SR + verbal prompt, maintenance, and generalization. SR involved positive reinforcement only, while SR + verbal prompt included a prompt for participants to engage in vocal rehearsal. Note that the performance of all three improved with training and the improvement maintained when treatment was removed during maintenance, as well as when untrained tasks were probed in generalization (Reproduced with permission from Elsevier)

The third study in this series by Baltruschat and colleagues (2012) evaluated reinforcement and multiple exemplar training to improve the accuracy of responding on another common test of working memory known as the *Digit Span Backwards* task. This task is similar to the tasks used in the previous studies in that the participant is said to simultaneously process and store the information provided. In this task, a span of auditory stimuli is presented and the participant

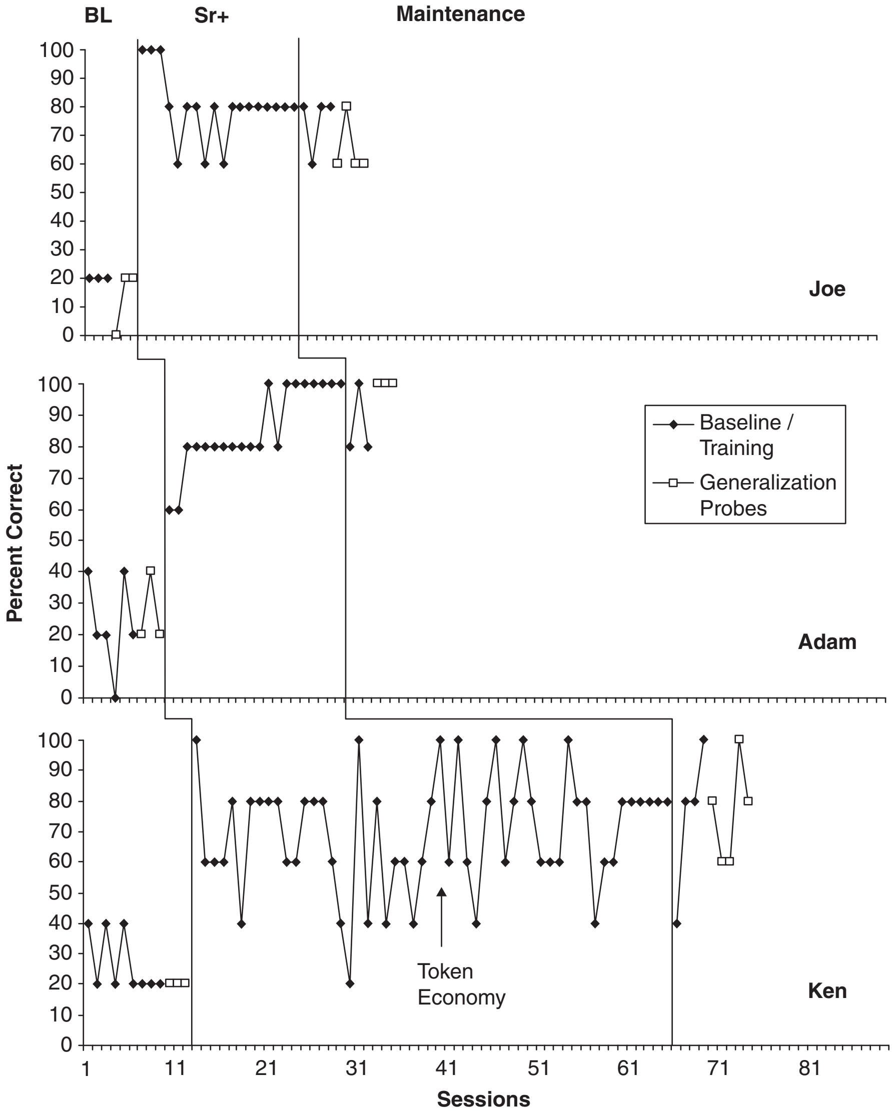

Fig. 5 Working memory performance from Baltruschat et al. 2012. Percentage of correct responding on working memory tasks for all three participants, during baseline, training, maintenance, and generalization. Training included positive reinforcement and the addition of a token system for Ken. Note that the performance of all three improved with training and the improvement maintained when treatment was removed during maintenance, as well as when untrained tasks (novel sequences of untrained letters) were probed in generalization (Reproduced with permission from the psychological record)

must recall the items in reverse order. Three children with autism, who had not been involved in the previous studies, participated. The procedure involved the presentation of a random string of three to four letters. Letters were selected randomly from a pool of eight letters for baseline, intervention, and maintenance sessions and from a pool of eight different letters for generalization sessions. As in the previous two studies, reinforcement was provided during the intervention phase contingent upon correct responding. Additionally, multiple exemplars of the three to four letter sequences were used during training. Reinforcement and multiple exemplar training resulted in improved accuracy on the *Digit Span Backwards* task, as well as maintenance once reinforcement was removed, and generalization to novel stimuli (Fig. 5). This study further extended existing research by showing that behavioral procedures can be implemented to improve performance on another, more complex test of working memory.

All three studies also included secondary analyses using pre- and posttest scores on the Arbeitsgedachtnis Testbatterie (AGTB; Hasselhorn et al. 2011). The AGTB is a computerized German test commonly used to measure working memory. In all three studies, participants showed posttest improvements on the AGTB. Stimuli used in this test were never present during the studies and further demonstrates generalization.

Future Research

The three studies described above provide a promising beginning for research in addressing working memory deficits in children with ASD. However, much work remains to be done. In the remainder of the chapter, directions for future research are discussed for the expansion of treatment research into multiple areas relevant to working memory treatment for individuals with ASD.

Age. The three studies by Baltruschat and colleagues included relatively young children with ASD. It is of course not known with any degree of certainty what neural structures are involved in working memory deficits, but it seems plausible that, whatever they are, their degree of neuroplasticity likely diminishes as children age. If this is the case, it seems likely that working memory intervention may become less effective as individuals with ASD get older. However, this possibility remains purely speculative until further research is done. Research is needed that replicates the same procedures with older children, adolescents, and young adults with ASD.

Clinical Interventions. The most important extension of any new area of treatment research is into the area of true clinical treatment. The studies described above were bridge studies, in that they applied proven behavioral procedures (multiple exemplar training and positive reinforcement) to a novel problem (working memory) in a clinical population. In this sense, the studies represented a first foray into identifying whether it was possible to affect working memory in children with ASD via positive reinforcement and multiple exemplar training, under well-controlled, ideal conditions. It was not the intention of the studies to produce a clinically significant outcome for the participants nor was such an outcome assessed. However, much other research in applied behavior analytic interventions for children with autism begins in well-controlled settings and progresses to real-life, community-based program evaluations (Cohen et al. 2006). This general model has proven effective with applied behavior analysis and autism, and there is no reason to believe the particular skill area of working memory will be different from the many other skill areas previously addressed by applied behavior analysis.

Several variables relevant to extending working memory intervention into clinically meaningful procedures warrant discussion. In particular, several variables make everyday episodes of working memory distinct from those involved in the three studies by Baltruschat and colleagues. First, the complexity of everyday use of working memory is far greater. Future research may benefit from systematically increasing the complexity of the working memory tasks involved, beginning with simple tasks and very gradually increasing the complexity of the tasks, for example, by gradually increasing the number, type, or novelty of stimuli involved. Similarly, the complexity of the context may need to be gradually increased from the relatively controlled setting of a room in the child's home to the relatively chaotic setting of the child's classroom. If these sources of complexity are increased slowly and only contingent on success at the previous level of complexity, it seems plausible that a real-life level of complexity may be reached successfully.

Second, the duration of the time delays involved in everyday applications of working memory may be greater than those included in the studies on working memory by Baltruschat and colleagues. For example, from the time the first stimulus in a series occurred to the time the child was later required to process the entire sequence of stimuli was probably never more than approximately 30 s. Everyday applications of working memory in the classroom might require time delays of 60, 90, or 120 s. Again, future research will likely benefit from gradually increasing the time delays until delays that are useful for everyday functioning are reached.

Third, executing working memory in situations involving everyday caregivers may be different from doing so in the presence of an experimenter with whom the child has a very specific history of learning to perform better on tests of working memory. That is, generalization of the effects of working memory training from the trainer to everyday caregivers may be a challenge. Children with ASD often have difficulty with generalization, and this is likely to be the case with working memory skills. Again, future research would do well to directly address this variable in order to ensure a positive clinical outcome. For example, including multiple different trainers in treatment is likely to help promote generalization across people. In addition, involving a child's mother, father, or nanny in training is likely to help promote generalization across family members.

Other Measures of Working Memory. Future research on treating working memory in individuals with ASD should explore a larger variety of measures of working memory. The studies described above employed three very different measures, so some degree of generality is likely, but much more research will be needed to confirm the generality of the findings. Other measures of working memory that could be investigated include the *Reading Span Task* and the

2-Back Task. In addition, employing standardized and validated measures of working memory, such as NEPSY-II (Korkman et al. 2007) and the BRIEF (Gioia et al. 2000), would help confirm the generality of the finding that interventions can affect working memory in general.

Long-Term Maintenance. Future research on interventions for working memory deficits in individuals with ASD should evaluate the long-term maintenance of any treatment effects observed. The final phase of all three studies by Baltruschat and colleagues was a maintenance phase that evaluated the extent to which treatment gains maintained when treatment was withdrawn. However, future research should evaluate maintenance of treatment effects for several months or longer.

Mediating Behaviors. Baltruschat and colleagues' (2011b) study specifically trained two of three participants to engage in verbal rehearsal, a behavior which was assumed to help mediate correct performance. Accurate rehearsal did indeed appear to promote accurate performance on the working memory task, and the participants were trained to inhibit vocal rehearsal aloud and instead "think it." Both participants were able to omit overt rehearsal and continued to respond well on the working memory task. These results provide initial support for the notion that rehearsal, both overt and covert, may facilitate accurate performance on working memory tasks, and that this skill can be taught to children with ASD. Future research should evaluate this possibility further, by explicitly targeting participants for whom positive reinforcement alone is not effective. Furthermore, it is possible that the level of complexity that could be reached could be increased by teaching accurate rehearsal.

Replication with Larger Samples. A significant limitation of any study with a small sample size is the threat to external validity. Each of the studies by Baltruschat and colleagues included only three participants, so future research should include larger sample sizes to help ensure external validity. However, modern standards for empirically supported treatments include a provision for single subject designs, generally requiring replication across three or more published single subject experiments, conducted by at least two or more different research groups (Chambless and Hollon 1998). Future research should employ both strategies to assess the external validity of behavioral intervention for treating working memory deficits in individuals with ASD.

Effects of Intelligence. All participants in the studies by Baltruschat and colleagues had well-developed verbal repertoires, and although few had recent results from intelligence tests that were available for study, it seemed likely through anecdotal observation that most had near-average intelligence. Future research should attempt to identify whether intelligence is associated with response-to-treatment in interventions for working memory deficits in children with ASD. There has been significant disagreement about the percentage of individuals with ASD who also suffer from intellectual disability, but most estimates agree that it is the majority of the population. Therefore, if near-average intelligence is associated with success in working memory treatment, this may imply that treatment may not be effective for the majority of children with ASD. This implication remains purely speculative and future research is needed to directly address it.

Interdisciplinary Collaboration. A casual review of research on the area of working memory in autism reveals a striking lack of collaboration between the various disciplines that are involved. In particular, neuropsychology and neuroscience have much to say about the structural and theoretical mechanisms behind working memory deficits, and these disciplines have done much to reveal the widespread deficits in working memory in ASD, but these disciplines have done little research in the area of treatment. Applied behavior analysis (ABA) is generally recognized as the chief discipline involved in autism treatment research, but ABA has largely ignored the area of working memory in particular and executive functions in general. It seems likely that future treatment research will be more fruitful if it is based on productive collaborations between all of the disciplines that have useful information to offer the problem of treatment of working memory deficits in individuals with ASD.

Conclusion

In conclusion, research on treating working memory deficits in individuals with ASD is still in its infancy. The vast majority of research on working memory in ASD continues to focus on identifying deficits, rather than treating them. However, the initial findings are promising. A series of three studies has been published by Baltruschat and colleagues that provides encouraging preliminary evidence that working memory performance can be improved via positive reinforcement and multiple exemplar training. However, much further research is still needed. Future research is needed to more fully expand the complexity and variety of working memory performances that can be improved, with the goal of more closely approximating the real-life working memory demands that individuals with ASD face on a daily basis. It is hoped that this chapter may provide a springboard for encouraging such future research, and it is believed that an interdisciplinary approach to such research is likely to be the most fruitful.

Key Terms

Executive Functions. The terms used to describe the collection of neural mechanisms thought to control goal-directed behaviors, such as planning, problem-solving, rule comprehension, and self-control, among others. These mechanisms are thought to include attention, working memory, and inhibition, among others.

Working Memory. The cognitive system required to take in information on an ongoing basis, keep the information online, and readily process it when needed a short time later.

Positive Reinforcement. The delivery of a reward as a consequence of a behavior, resulting in a strengthening of that behavior in the future.

Multiple Exemplar Training. Delivering positive reinforcement for a large variety of different behaviors that belong to a particular class, which results in the strengthening of the entire class. Teaching many examples of a concept, resulting in the learner being able to apply the newly learned concept in a generalized manner.

Generalization. The spreading of the effects of an intervention or teaching procedure to other stimuli, settings, people, or examples than the ones present during the intervention. Generalization can be produced through multiple exemplar training.

Key Facts of Working Memory Tasks

- All working memory tasks test a person's ability to keep information online and process it a short time later generally while inhibiting distractions of some sort.
- Working memory tasks can be presented by a person or by a computer.
- **Counting Span** tasks require a person to count the number of objects he/she sees on a series of stimulus presentations and later recall all the counted quantities in the order in which they were presented.
- **Complex Span** tasks require a person to respond to a series of stimuli by classifying them in some way, for example, by answering a question "Can you eat it?" After the series of stimuli has been presented, the participant is asked to recall all of the stimuli in the order in which they were presented.
- **Digit Span Backwards** tasks require a person to listen to a series of random letters or numbers and then repeat them back to the tester in the reverse order to how they were presented.

Summary Points

- Individuals with autism have documented deficits in executive functions in general and working memory in particular.
- Baltruschat and colleagues conducted a series of three studies to evaluate the use of behavioral procedures to improve performance on three common tests of working memory with children with autism: the *Counting Span*, *Complex Span*, and *Digit Span Backwards* tasks.
- The three studies by Baltruschat and colleagues used positive reinforcement in the context of multiple exemplar training.
- This series of studies demonstrated that behavioral procedures can improve accuracy on tasks involving working memory, as well as maintenance and generalization to novel stimuli.
- The research on treatment for working memory in individuals with autism is in its infancy but has produced highly encouraging results thus far.
- More research is needed to further investigate how treatment for working memory can be expanded to more complex tasks that more closely resemble working memory episodes that individuals with autism are faced with in their daily lives.

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