Chapter 6
Psychological Assessments in Physical Exercise

Marcel Daamen and Markus Raab

Abstract This chapter will present a short review of psychological assessment techniques which are frequently used to measure cognitive and affective functions. If available, these measurement approaches are illustrated with examples from recent sports- and exercise-related studies. In addition, the chapter will discuss important caveats and methodological perspectives and that may be relevant for future studies in this research field, especially in the context of neuroimaging applications.

6.1 Introduction

The development of modern neuroimaging techniques, such as magnetic resonance imaging (MRI), positron emission tomography (PET), and near-infrared spectroscopy (NIRS), along with technical improvements in electroencephalography (EEG), has provided us with methodological tools that give unprecedented insights into human brain function. In recent years, researchers have also started to utilize these methods to elucidate the physiological mechanisms that mediate the acute and chronic influences of physical exercise on human brain function. Yet, to appraise the functional significance of physiological effects that are observed with these neuroimaging tools, they should be correlated with complementary observations of psychological and behavioral outcome measures. Accordingly, the careful selection

M. Daamen (✉)
Functional Neuroimaging Group, Department of Radiology, University of Bonn,
Sigmund-Freud-Str. 25, 53105 Bonn, Germany
e-mail: Marcel.Daamen@ukb.uni-bonn.de

M. Raab
Institute of Psychology, German Sport University Cologne,
Am Sportpark Müngersdorf 6, 50933 Cologne, Germany
e-mail: Raab@dshs-koeln.de

H. Boecker et al. (eds.), *Functional Neuroimaging in Exercise and Sport Sciences*,
DOI 10.1007/978-1-4614-3293-7_6,

of psychological and behavioral measures is a methodological issue that is also relevant for designing neuroimaging studies aimed at understanding the effects of exercise on brain function.

This chapter will provide a short review of psychological assessment techniques, concentrating on psychological functions that play a prominent role in the recent exercise-related neuroscience literature. These functional domains are divided into two broader classes: *Cognitive functions* and *affective functions*. After providing brief outlines of key theoretical concepts that are central for our current understanding of these functional domains, we review assessment techniques that are typically used to operationalize these psychological constructs. If possible, the approaches will be illustrated with relevant sports- and exercise-related studies, and we will discuss methodological perspectives that may be interesting for future studies. The final section will conclude with some general considerations for the practical use of psychological tests, including possible applications in, and adaptations to, neuroimaging studies.

6.2 Cognitive Functions

In recent years, the relationship between physical activity and cognitive function has received considerable attention (Hillman et al. 2008; Etnier 2009). There is accumulating evidence that behavioral interventions that aim to increase physical fitness can have a beneficial effect on cognitive function in older adults (Colcombe and Kramer 2003). This observation has important public health implications, as regular physical activity may help to protract age-related cognitive decline, or ameliorate the progression of dementia disorders (Etnier 2009). In addition, recent studies suggest that physical fitness may also influence cognitive development in children and adolescents (Hillman et al. 2008; Chaddock et al. 2010).

Although there are several cognitive domains that might be influenced by exercise-induced brain changes, this review will mainly concentrate on four specific aspects which are frequently assessed in contemporary exercise-related studies: *short-term and working memory*, *long-term memory*, *attention*, and *executive control functions* (see Table 6.1, for a short overview). In addition, we will include a short discussion on *global cognitive measures*. Although these measures do not necessarily qualify as sensitive outcome variables, the global functional level of an individual can be an important background characteristic (e.g., as a confounding or moderator variable).

6.2.1 General Background

Most contemporary models of higher mental functions (e.g., attention, vision, memory, and language) are based on the *cognitive processing approach*, which means that they conceptualize the human mind as an information processing

Table 6.1 Cognitive domains, task formats and exercise-related applications

Functional domain	Typical paradigms	Exercise-related applications
Working memory		
• *Short-term retention*	Forward digit span	Voss et al. (2010)
• *Manipulation*	Backward digit span	Voss et al. (2010)
• *Updating*	N-back	Stroth et al. (2010)
• *Inhibition*	Operation span, reading span	Sibley and Beilock (2007)
Long-term memory		
• *Declarative*	Word list learning and retrieval	Pereira et al. (2007)
	Story recall	Stroth et al. (2009)
	Associative learning	Chaddock et al. (2010)
• *Nondeclarative*	Implicit word stem completion	Eich and Metcalfe (2009)
Attention		
• *Intensity*	Simple reaction time	Smiley-Oyen et al. (2008)
	Sustained attention (e.g., CPT)	Del Giorno et al. (2010)
• *Selectivity*	Visual search (e.g., TMT-part A)	
	Cancellation tests	Stroth et al. (2009)
	Digit symbol coding (e.g., DSST)	Williamson et al. (2009)
	Global-local processing	Pesce et al. (2007)
	Divided attention (e.g., PASAT)	Del Giorno et al. (2010)
Executive control functions		
• *Set shifting*	Wisconsin card sorting test	Dietrich and Sparling (2004)
	TMT-part B	
	Task-switching paradigms	EEG: Themanson et al. (2006)
• *Inhibition*	Stroop task	Smiley-Oyen et al. (2008)
	Eriksen Flanker task	EEG: Themanson and Hillman (2006)
		fMRI: Colcombe et al. (2004)
	Go/Nogo tasks	Smiley-Oyen et al. (2008)
	Stop signal task	Kramer et al. (1999)

TMT Trail-making test, *DSST* Digit symbol substitution test, *CPT* Continuous performance test, *PASAT* Paced auditory serial addition test, *EEG* electroencephalography, *fMRI* functional magnetic resonance imaging

system that analyzes incoming sensory stimuli, evaluates the sensory input in comparison to stored memory representations, and uses the information to plan, generate, and regulate appropriate behavioral responses (Audiffren 2009; Tomporowski 2009). Psychological functions are interpreted as the product of latent cognitive processes that are not accessible to direct observation or subjective experience, but have to be inferred from behavior. Typically, this is achieved by analyzing the consequences of task manipulations on behavioral output parameters, such as reaction times and error rates. While cognitive sciences show a traditional focus on verbal and overt motor responses (e.g., buttons presses), it should be noted that there are several other response modalities available, including psychophysiological measures (e.g., skin conductance, electromyography, blood pressure, and heart rate responses).

6.2.2 Short-term and Working Memory

The assumption that memory is not a unitary faculty, but can be divided into some kind of *short-term memory*, which keeps a limited amount of information highly accessible for a time frame of a few seconds, and *long-term memory*, which is theoretically capable to store unlimited amounts of information for days, weeks, and years, became especially popular with the advent of cognitive psychology, and is a key aspect of the influential "modal model" of memory (Atkinson and Shiffrin 1968). Building on the idea that short-term memory is a store with limited capacity, short-term memory tasks typically probe *how much* and *how long* information can be maintained. A classic example is the *forward digit span task*, which is included both in the *Wechsler Memory Scales* (*WMS*: Wechsler 2009) and *Wechsler Adult Intelligence Scale* (*WAIS*: Wechsler 2008): In this task, orally presented sequences of digits have to be repeated in identical order (e.g., "5-6-2-9" → "5-6-2-9"), and the length of the sequences is increased incrementally to determine the maximum number of elements that can be repeated correctly.

While the classical concept of human *working memory* (Baddeley and Hitch 1974) is based on the distinction between short-term and long-term memory, it emphasizes that short-term memory is not just a passive store that maintains information, but serves as an active workspace for a wide range of complex cognitive operations. Therefore, this model not only introduces modality-specific short-term storage systems (a "phonological loop" for verbal information, a "visuospatial scratchpad" for visual object and spatial information, and an "episodic buffer", which interfaces the other short-term stores with long-term memory). Moreover, the model adds a "central executive" component, which is thought to regulate inflow and active manipulation of information within these short-term memory stores, and their interactions with long-term memory (see Baddeley 2003, for a more comprehensive review).

The functional differentiation between storage and regulatory processes has implications for the practical measurement of working memory: While traditional short-term memory measures are mainly focused on the temporary maintenance of information, human working memory paradigms typically include additional task requirements that call for some kind of top-down control. For example, these requirements may encompass the active manipulation of items that are currently represented in short-term memory. Classical examples are the *WAIS backward digit span task*, where sequences of orally presented numbers have to be recalled in the reversed order (e.g., "5-6-2-9" → "9-2-6-5"), or the *WAIS letter–number sequencing task*, where sequences of letters and numbers are presented randomly but have to be reproduced in alphabetical and numerical order (e.g., "D-4-A-3" → "A-D-3-4": Wechsler 2008). Other tasks require a continuous updating of stored information, for example in *N*-back tasks, where series of items (e.g. letters, numbers, geometric figures) are presented one at a time, and subjects have to indicate whether the *current* item is identical to the item presented *N* trials (typically 1, 2 or 3) *before* (Lezak et al. 2004). Other paradigms capture the ability to suppress interfering information that is presented during retention intervals. Typical examples are *reading span* and *operation span tasks* (Miyake et al. 2000; Sibley and Beilock 2007), where subjects have to memorize a sequence of items, but critically, these relevant items are interleaved with distracting information, for example by reading short sentences or completing mathematical operations.

Many of the earlier exercise-related studies were unable to find associations between exercise and "working memory" functions, both on the acute (Coles and Tomporowski 2008; Tomporowski and Ganio 2006, but see Pontifex et al. 2009) and chronic level (Smith et al. 2010). On the one hand, it is possible that physical exercise had effects on task performance that were too subtle to be substantiated with these behavioral measures: Here, neuroimaging techniques may provide a more sensitive tool (e.g., EEG—see also Chap. 18). On the other hand, the failure to find behavioral changes may be partially attributable to the predominant use of classic short-term memory paradigms that primarily measure the temporary maintenance of information (e.g., digit span tasks). It was suggested that working memory paradigms may provide a more sensitive target for investigation, since they additionally tax the central executive (McMorris 2008; McMorris et al. 2011), but this will have to be corroborated in future studies.

In addition, the quality of the maintained information may play a decisive role, because this has a necessary influence on the brain circuits that are critically implicated in information storage. Traditionally, short-term memory functions were primarily associated with fronto-parietal, neocortical networks (Baddeley 2003). Since global amnesic patients with hippocampal damage typically show normal performance in traditional short-term memory tasks (e.g., digit span), it was assumed that the human hippocampus plays no significant role in short-term memory, but is primarily involved in the transfer of declarative information from short-term into long-term memory (Nadel and Hardt 2011). Meanwhile, there is recent neuropsychological and neuroimaging evidence that the hippocampus does participate in certain short-term memory functions, although this may only become apparent in specific task settings where the retention of situation-specific configurations or associations between distinct items (e.g., spatial relations of objects in spatial memory tasks) is important to discriminate between similar stimuli (Bird and Burgess 2008; Nadel and Hardt 2011). Considering the various animal studies that found a modulating effect of regular physical exercise on hippocampal function and spatial memory performance in rodents (Cotman et al. 2007; see also Chap. 1), it can be speculated that complementary links may also be present in humans, given that appropriate task material is used. Consistent with this view, a cross-sectional study with older adults found that the physical fitness level was correlated with the performance in a spatial memory task that measured the short-term retention of the positions of one, two, or three dots in a random spatial arrangement: Critically, the statistical relationship was mediated by the hippocampal volumes, as obtained from structural MRI data (Erickson et al. 2009; see also Chap. 17). These findings suggest that this specific kind of short-term memory paradigm (or similar paradigms presenting complex relational information) provides an interesting tool for future studies. In particular, functional neuroimaging data are needed to test whether physical fitness differences in hippocampal volume translate into differential brain activation patterns during the performance of this kind of paradigm.

6.2.3 Long-term Memory

Long-term memory refers to the ability to maintain and retrieve information about past experiences that happened minutes, days, months, or years ago. The appearance of these long-term memory abilities is quite heterogeneous, and the available psychological and neuroscientific literature suggests that they do not reflect the labor of a unitary faculty, but are the products of multiple memory systems that work in parallel, and are specialized for the acquisition, storage, and retrieval of different kinds of information (Squire 2004; Nadel and Hardt 2011). There is a broad consensus that long-term memory contents can be dichotomized into at least two broader domains: *declarative* and *nondeclarative memory* functions (e.g., Squire 2004).

6.2.3.1 Declarative Memory

Declarative (or explicit) memory refers to those forms of long-term memory where the recall of information causes a subjective feeling of "knowing" or "remembering" (e.g., Squire 2004). It encompasses *semantic memory*, which contains the factual knowledge that we acquire about regularities in our world (e.g., what a chair looks like and what to do with it, "Paris is the capital of France," "2+2=4"), and *episodic memory*, which contains our recollections of unique events that we experience as our own past (e.g., marriage, birth of a child, burial of a close friend).

Most of the available standardized tests for long-term memory are related to declarative memory: Subjects are explicitly asked to memorize presented stimulus material and deliberately try to remember the material after a specified time delay. While a variety of materials are used (e.g., abstract visual stimuli, geometric figures, faces, objects, sounds; see Lezak et al. 2004; Strauss et al. 2006, for more detailed reviews), many of the common long-term memory tests are based on the oral presentation of verbal stimuli, especially word lists (e.g., the *Rey Auditory Verbal Learning Test*, RAVLT) and story passages (e.g., the *WMS Logical Memory subtest*: Wechsler 2009). In many cases, the presentation and subsequent retrieval of the same material is repeated over multiple trials, which allows measuring learning curves (e.g., the number of trials necessary for learning the complete stimulus set). Retrieval performance can be tested immediately after presentation of the material, or after a certain delay (typically in the range of several minutes): Notably, delayed retrieval provides a more reliable indicator of long-term memory, as the time gap reduces the possibility that reproduced items are actually recalled from short-term memory (which would be possible for items that were presented immediately before retrieval).

Turning to the exercise-related literature, many earlier reviews found little evidence for a modulating influence of *acute* physical exercise on declarative long-term memory (e.g., Tomporowski 2009), but an updated meta-analysis (Lambourne and Tomporowski 2010) has challenged this conclusion: In fact, recent studies suggest that exercise-induced arousal can indeed have a beneficial effect on declarative learning and memory, at least *after* acute bouts of exercise (e.g., Winter et al. 2007; Coles and Tomporowski 2008, but see Eich and Metcalfe 2009). From a methodological perspective, it is interesting that positive findings were mainly found for demanding memory paradigms (e.g., by asking subjects to learn associations between pseudowords and familiar objects, or by presenting a 40-item word list only once before testing free recall), indicating that the modulating effects are subtle and may only become apparent in sufficiently difficult task conditions.

Meanwhile, there is substantial evidence for a link between *chronic* exercise and long-term memory function: On the one hand, rodent studies have shown that chronic exercise regimens can improve learning and memory performance in a variety of long-term memory tasks that are known to depend on hippocampal function, and there is accumulating evidence that hippocampal plasticity processes play a key role in the expression of these exercise-induced memory effects (Cotman et al. 2007; see also Chap. 1). On the other hand, a plethora of neuropsychological data from brain-damaged patients indicates that the human hippocampus (and surrounding regions of the medial temporal lobe) is especially critical for the acquisition of declarative long-term memory representations. In fact, behavioral performance in declarative memory tests is traditionally used to make inferences about hippocampal function in clinical patients (Bird and Burgess 2008; Squire 2004; Nadel and Hardt 2011). Therefore, observations from exercise-related studies which found positive associations between regular physical activity and declarative memory performance (e.g., Pereira et al. 2007; Stroth et al. 2009; Smith et al. 2010) may be interpreted as indirect evidence for a facilitating effect of physical exercise on human hippocampal function. Corroborating this view, one of these studies (Pereira et al. 2007) provided initial human evidence for a direct link between improved hippocampal function and verbal declarative memory (see also Chap. 16).

While the above-mentioned investigations used standard memory tests (e.g., word list learning paradigms), it is interesting to note that recent behavioral studies have adapted experimental paradigms that were originally developed to provoke hippocampal activations in functional neuroimaging studies: For example, two recent studies with preadolescent children tested the learning and subsequent recall of novel, arbitrary associations between faces and houses (Chaddock et al. 2011), or between triplets of senseless fractal images (Chaddock et al. 2010). They found that children with lower fitness levels showed a specific deficit in the associative learning of the *item combinations*, but not in *single-item* recognition. Intriguingly, one of these studies (Chaddock et al. 2010) found that the association between fitness and relational memory was mediated by hippocampal volume. These findings concur with classical neuropsychological theories that emphasize the central role of the hippocampus for the long-term storage of complex object associations and relations (Bird and Burgess 2008; Nadel and Hardt 2011), and are compatible with the above-mentioned observations by Erickson et al. (2009), although it has to be acknowledged that the retention intervals in the latter study (~3 s) were only tapping short-term retention. Again, it would be interesting to test whether brain activation patterns *during* the performance of these paradigms show complementary physical fitness effects. While there is still a general lack of functional neuroimaging studies that investigated the influence of exercise on declarative memory functions, this seems to be a promising starting point.

6.2.3.2 Nondeclarative Memory

In contrast to declarative memory, the activation of nondeclarative (or implicit) memory representations causes no subjective memory experience but is expressed implicitly, by changes in behavioral performance that would not appear without practical experience with the task at hand. The most dramatic support for this claim comes from amnesic patients who show training-related behavioral changes in many nondeclarative memory tasks but have no declarative memories of the training sessions (e.g., Graf and Schacter 1985; Foerde 2010). This class of memory functions encompasses a heterogeneous variety of abilities, such as *motor skills* (e.g., swimming, riding a bicycle) and *perceptual skills* (e.g., mirror reading), *perceptual* and *conceptual priming* (i.e., facilitated perceptual or semantic processing of a stimulus after experience with this specific stimulus), *habit learning* (i.e., the feedback-based learning of automated stimulus–response associations), and simple forms of *Pavlovian conditioning* (e.g., learned fear responses) (Squire 2004; Foerde 2010).

To date, nondeclarative memory tests are virtually lacking in the sports and exercise literature. In a rare exception, Eich and Metcalfe (2009) tested marathon runners with a so-called *implicit word stem completion task* (Graf and Schacter 1985): Subjects were initially asked to rate the pleasantness of a presented word list (e.g., *sport*, *flower*,…). Most importantly, no reference was made to the retention of the material which would be subsequently tested. Next, the experimenters presented a list of three-letter word stems (e.g., SPO__, FLO___), and subjects were instructed to complete them with the first words that came to their mind. Critically, half of these word stems belonged to words that were taken from the previously rated list. Although this fact is never made explicit in this kind of paradigm, participants will sometimes complete these word stems with corresponding items from the previous word list (e.g., SPO__→*sport*, FLO___→*flower*), which is interpreted as an implicit (i.e., incidental, automatic) retrieval of the familiar material that is probably facilitated (or "primed") by the previous activation of the respective word representations during rating. Although they are not explicitly instructed to recall the word list, it is possible that participants just recognize the items spontaneously (i.e., show an incidental recall from declarative memory). Therefore, the final experimental condition presented another list of word stems which were all derived from the other half of the word list, and participants were explicitly instructed to complete the word stems with items from the previous list (i.e., the word stems were used to provoke *cued recall* from declarative memory). Intriguingly, previous studies using this paradigm indicate that amnesic patients fail to remember the word list items deliberately in the declarative recall condition, but perform similar to controls in the implicit recall condition (e.g., Graf and Schacter 1985). This functional dissociation suggests that explicit and implicit recall depend on divergent memory processes, which may show a differential sensitivity for alterations of brain function. In fact, Eich and Metcalfe (2009) found that runners who were tested immediately after a marathon showed a *weaker* explicit, but *better* implicit recall than a control sample of marathon runners who were tested before completing a marathon. These divergent effects suggest that the strenuous exercise regimen exerted opposing subacute effects on declarative and nondeclarative memory performance, possibly via neurohumoral stress mechanisms that may facilitate some brain systems, and inhibit others (Eich and Metcalfe 2009).

Possibly, there are other forms of nondeclarative memory that may also prove to be sensitive to the effects of physical exercise, but this has not, to the best of our knowledge, been tested directly. For example, it may be worthwhile to investigate the *feedback-based learning of probabilistic stimulus–response associations*: In these paradigms, correct responses have to be learned by trial and error feedback, which is thought to be strongly associated with dopaminergic function, especially in the basal ganglia (Foerde 2010). Although the available evidence is mainly based on clinical populations, especially patients with Parkinson's disease (Shohamy et al. 2008), it would be interesting to speculate about the possible impact of exercise-induced acute changes in dopaminergic neurotransmitter release, which are discussed in the recent literature (e.g., McMorris 2008), on performance in this kind of task.

6.2.4 Attention

Attentional mechanisms are ubiquitous to cognitive processing. Given that a vast number of sensory inputs, activated memory representations, and internally generated thoughts are continuously streaming into consciousness and compete for the available processing resources, the cognitive system must select those information aspects that are currently most relevant for adaptive behavior, and neglect, or even suppress, representations that are irrelevant. This attentional selection process is often compared with a spotlight, and although this analogy is most appropriate for the specific case of visuospatial attention processes, it provides a nice illustration of two basic characteristics which are typically measured with attentional tasks: *intensity* and *selectivity* (van Zomeren and Brouwer 1994).

6.2.4.1 Intensity of Attention

The intensity aspect of attention relates to the varying amount of attentional resources that are available for energizing sensory and cognitive processing, which can, metaphorically speaking, be compared to the brightness of a spotlight (van Zomeren and Brouwer 1994). These energizing mechanisms are somewhat neglected by modern theories of attention, but there is a long tradition of neurophysiological studies which indicate that the mesencephalic reticular formation and its diffuse afferent projections to various higher brain regions (which are collectively known as the ascending reticular activation system, ARAS) are crucial for the regulation of the brain activation level (see Audiffren 2009; van Zomeren and Brouwer 1994, for detailed reviews).

This activation (often referred to as "arousal") is thought to determine the alertness level, that is, the preparedness of an organism to respond to external stimuli, or in terms of cognitive models, the basic processing speed of the information processing system. The current alertness level is typically measured with task formats that include only elementary stimulus detections or discriminations, such as *simple reaction time tasks*, where the appearance of a specific target stimulus (e.g., a tone or a visual stimulus) is associated with a single response option (e.g., a button press), as compared to *choice reaction time tasks*, where discriminative responses for different stimuli have to be made (van Zomeren and Brouwer 1994; Lezak et al. 2004; McMorris 2008). As these tasks afford a minimum of sensory and motor processing (without complex cognitive operations that could delay the response), systematic variations in reaction time are supposed to reflect latent differences in the brain arousal level. Although alertness is often measured for task blocks of a few minutes' duration, it is also possible to extend the task duration (from several minutes up to hours), which creates sustained attention tasks, such as the *Continuous Performance Test*, where participants have to react to target stimuli which are randomly interspersed into streams of distractor items (van Zomeren and Brouwer 1994).

Brain arousal is a key variable in many explanatory models for the *acute* cognitive effects of physical exercise: They assume that physical exercise modulates the intrinsic brain activation systems, which broadens (or narrows) the basic energetic resources available for information processing (e.g., "cognitive-energetic" approaches: McMorris 2008; Audiffren 2009). Probably, these modulating effects are mediated by a homeostatic cascade of neuroendocrine adaptations (both in the periphery and in the brain), which eventually increase ARAS transmitter release, especially for dopamine (DA) and norepinephrine (NE: e.g., McMorris 2008). The relationship between exercise, arousal, and cognition is often described by an inverted U-curve function (*Yerkes–Dodson law*). In this model, low levels of activation (e.g., during sleepiness, fatigue) are considered suboptimal for cognitive processing. Moderate aerobic exercise is thought to increase the activation level, which optimizes the stimulation level for improved information processing. In contrast, strenuous (e.g., anaerobic) forms of exercise are supposed to generate extreme levels of brain arousal that cause overstimulation and hence, degradation of processing efficiency. Unfortunately, the available literature provides only limited evidence for this simple kind of dose–response relationships, although it has to be acknowledged that the heterogeneity of the studies (e.g., regarding specific task demands, exercise duration or intensity) complicates firm conclusions (see McMorris 2008, for a more detailed discussion of factors which may contribute to these conflicting results).

In addition, the use of reaction time measures as a behavioral indicator for exercise-induced arousal suffers from certain methodological drawbacks. This interpretation is generally hampered by the fact that reaction time (which is usually defined by the time window between stimulus onset and detection of the overt reaction, e.g., a button press) conflates the influences of several processing stages, including stimulus identification, response selection, but also response *execution*. Thus, faster response times after acute exercise might not (or not only) reflect speeded information processing on the brain level, but also faster electromechanical signal transduction in the peripheral motor pathway (McMorris et al. 2011). This assumption is supported by recent studies that complemented reaction time paradigms with electromyographic (EMG) measurements of peripheral motor activity (see Davranche and Audiffren 2009, for a review). An alternative strategy, which circumvents contamination with motor processes and gives *direct* insights into processing speed on the brain level, is the EEG acquisition of event-related potentials (ERP), which can, for example, be analyzed for amplitude and latency differences (see also Chap. 18).

6.2.4.2 Selectivity of Attention

Modern theories of attention usually emphasize the selectivity aspect of attention, that is, the focusing (or distribution) of the available attentional resources on specific stimuli or stimulus attributes. Metaphorically speaking, this corresponds to the beam radius of the attentional spotlight, which can be zoomed out or in for a broader or narrower view, and shifted in different spatial directions (van Zomeren and Brouwer 1994). This attentional selectivity is supposed to be regulated by both involuntary and voluntary mechanisms. A practical example of an involuntary attentional selection is the orienting response, where novel, unexpected, intense, or biologically significant external stimuli automatically shift attention in the spatial direction of the critical stimulus (van Zomeren and Brouwer 1994). Yet, most tests for attentional function assess the *voluntary* control of selective attention, for example, the ability to "concentrate" on task-relevant stimuli or response options.

There is a whole variety of task paradigms which are difficult to categorize into one comprehensive taxonomic framework. Hence, the following paragraphs can only present some typical examples for this test category (for more extensive reviews, see van Zomeren and Brouwer 1994; Strauss et al. 2006).

A traditional method for measuring selective attention is the use of *visual search* and *cancellation tests*, where subjects have to find critical target stimuli under speeded testing conditions (van Zomeren and Brouwer 1994; Lezak et al. 2004; Strauss et al. 2006): For example, in the *Trail-Making Test Part A* (TMT-A), a set of numbered circles distributed in a random spatial arrangement are presented, and subjects are instructed to connect these numbers in ascending order (Fig. 6.1). While the TMT-A allows subjects to shift attentional focus in a self-determined manner, *cancellation tasks* typically present structured displays (e.g., rows with random sequences of letters or digits) and ask subjects to scan this stimulus display systematically (e.g., line by line) to mark a specified class of target stimuli (e.g., mark all *Fs* and *Rs*).

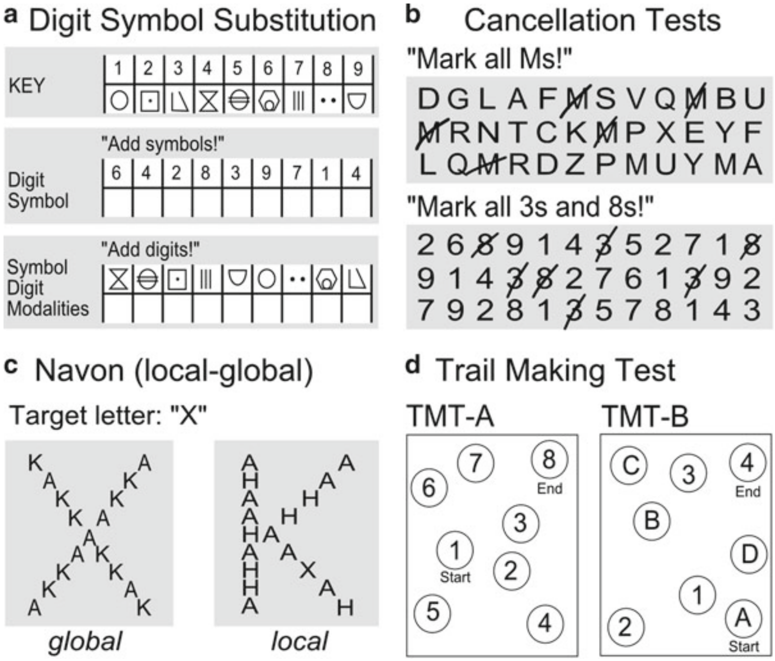

Fig. 6.1 Examples for attentional tasks. Schematic description of stimulus characteristics. See text for details

The ability to control the attentional focus is also critical for successful performance in another classical concentration test format, the *WAIS Digit Symbol Substitution Test* (DSST: Wechsler 2008), and the analogous *Symbol Digit Modalities Test* (SDMT: Smith 1982). Both tasks present a table that assigns each of the digits 1–9 to a specific, nonsense geometrical figure (see Fig. 6.1). Subjects are provided with random series of digits (DSST) or geometric figures (SDMT) and have to write down as many corresponding symbols (DSST) or numbers (SDMT) as possible in a given amount of time. At least in the initial phase (before the transformation rules may be incidentally learned), subjects have to continuously shift attentional focus between table and stimulus rows to look up the correct assignment.

Meanwhile, some experimental paradigms assess the adaptive *zooming* (i.e., broadening and narrowing) of attentional focus, for example, by assessing the ability to attend to local and global stimulus features in so-called *Navon figures* (Navon 1977; see also Miyake et al. 2000). Here, the spatial arrangement of a group of small stimuli forms the global impression of a larger stimulus (e.g., several *A* and *K* letters that make up a large *X* letter; see Fig. 6.1). A series of exercise-related studies (e.g., Pesce et al. 2007) utilized this kind of stimuli: Subjects had to decide whether the presented stimuli contained a predefined target letter, which could be present either at the local level (i.e., as one of the small letters) or at the global level (i.e., as the large letter). Critically, the attentional focus was systematically manipulated by visual warning cues that indicated the probable location of the upcoming target letter.

In one condition, a *large* square cued the probable appearance of a *global* target stimulus, while *small* squares at a specific spatial position cued the probable appearance of a *local* target letter in this position. Thus, the physical size of the cue stimulus automatically zooms the attentional focus to the probable target location. In contrast, the other task condition put a stronger emphasis on “top-down” attentional control: Here, the *large* square cued the probable appearance of a *local* target, and the *small* square cued the appearance of a *global* target, which means that the automatic tendency to adapt the attentional zoom according to the physical size of the cue has to be overridden by voluntary control.

Finally, some paradigms measure *divided attention*, that is, the ability to distribute the available attentional resources, or move the attentional focus, over different stimuli or mental operations (van Zomeren and Brouwer 1994). These tasks are based on the assumption that the structural and energetic capacities of the information processing system are limited, which means that task situations that involve the parallel execution of several cognitive operations can induce interference, as the different processes may compete for the same processing resources. Divided attention is usually tested in *dual-task situations*, for example, by asking subjects to concurrently detect the appearance of target stimuli in two different streams of stimuli (van Zomeren and Brouwer 1994; Lezak et al. 2004). Another popular instrument is the *Paced Auditory Serial Addition Task* (PASAT: Gronwall 1977; Lezak et al. 2004): Here, random sequences of digits are presented, and subjects are instructed to continuously add the current digit to the digit that was presented immediately before (e.g., 5-7-3 → 5 + 7 = *12* and 7 + 3 = *10*). Additionally, task difficulty is manipulated by changing the tempo of stimulus presentation.

Divided attention is especially relevant for studies that examine cognitive function during acute exercise, as varying requirements of ongoing motor control (e.g., for running, as compared to cycling) may produce different levels of interference with the concurrent processing of the cognitive task (Lambourne and Tomporowski 2010). Critically, interference can eventually resolve in situations where overtraining automates the execution of one task component and leaves the redundant attentional resources for the execution of the concurrent task. As a consequence, the acute effects of an exercise bout may vary for inexperienced as compared to skilled athletes, but also depending on familiarity with the presented cognitive task: Such background differences in task proficiency may contribute to the variable findings of studies which examined cognitive performance during acute exercise (see Lambourne and Tomporowski 2010, for a more detailed discussion).

6.2.5 Executive Control Functions

The concept of executive control functions is an umbrella term for a class of “higher level” cognitive functions that are thought to regulate subsidiary sensory, cognitive, emotional, and motor processes in a supervisory (or “top-down”) manner. They enable the planning, execution, and monitoring of complex goal-directed behavior, especially in novel situations where no automated behavioral scheme is available, or where available behavioral schemes must be adapted to cope with changing situational demands (Gazzaley and D'Esposito 2007; Jurado and Rosselli 2007; Strauss et al. 2006).

The notion of executive control functions was already briefly introduced in previous sections: For example, the idea of supervisory control is especially salient in the "central executive" concept of Baddeley's working memory model (Baddeley 2003), which explains why working memory is often referred to as an executive control function (Miyake et al. 2000; see also: McMorris et al. 2011). Moreover, supervisory control processes are frequently used to explain the voluntary "top-down" regulation of attentional resources, especially in focused or divided attention tasks (van Zomeren and Brouwer 1994). While performance in many of the above-mentioned task paradigms is probably influenced by executive control, they mainly emphasize the subsidiary cognitive domains (i.e., attention and memory). Therefore, the following section will present some task paradigms that aim to operationalize executive control function more directly.

Traditionally, the concept of executive control is closely linked with the prefrontal cortex (PFC: Strauss et al. 2006; Stuss 2007): This region shows extensive synaptic connections (both excitatory and inhibitory) with a broad range of cortical and subcortical structures, which enables the PFC to both amplify *and* suppress neural activity in these associated brain circuits in a "top-down" fashion. From this neuroanatomical perspective, the PFC should be able to modulate a broad range of sensory, cognitive, emotional, and motor processes (Gazzaley and D'Esposito 2007; Miller and Cohen 2001). While the association between the frontal lobes and executive control functions as a psychological *construct* is generally accepted, there are some methodological complexities which have to be considered when measuring this psychological construct with so-called executive control or frontal lobe function *tasks* (for detailed discussions, see Jurado and Rosselli 2007; Stuss 2007): For example, many of the traditional tests are *sensitive*, but not *specific* to frontal lobe dysfunction, as damage in non-frontal (e.g., parietal) brain regions can also impair task performance, probably by interfering with those subordinate processes that are controlled by executive control functions. Thus, performance in these task cannot automatically be interpreted as an indicator of frontal lobe (dys)function (Stuss 2007; Strauss et al. 2006).

Moreover, traditional paradigms usually concentrate on the regulation of *cognitive* processes (i.e., cognitive control), and are mainly sensitive to *dorsolateral* (DLPFC) and *dorsomedial prefrontal* (DMPFC) damage: In contrast, patients with *orbital* (OFC) or *ventromedial* prefrontal (VMPFC) damage are often not affected in cognitive control, but show prominent impairments in behavioral and emotional self-regulation (Stuss 2007). This indicates that the ventral prefrontal regions show a different functional specialization, although it has to be acknowledged that there is still a paucity of standardized tests which can quantify these deficits reliably (Zald and Andreotti 2010). In practice, scientists need to be aware that none of the available tasks that aim to measure executive control functions actually provides a *global* indicator for frontal lobe function.

Unfortunately, the specific characteristics of the executive control mechanisms remain elusive (Jurado and Rosselli 2007; Etnier and Chang 2009). While some theories propose a unitary control mechanism (e.g., active maintenance of task-relevant information: Miller and Cohen 2001), many researchers prefer a functional system with distinct processes that cooperate flexibly to regulate behavior (e.g., Miyake et al. 2000; Stuss 2007). Unfortunately, there is no comprehensive taxonomy for these processes: Rather, there are a variety of alternative classifications, for example, volition, planning, purposeful action, and effective performance (Lezak et al. 2004); planning, scheduling, inhibition, and working memory (Colcombe and Kramer 2003); or shifting, updating, and inhibition (Miyake et al. 2000). In addition, successful performance in many of the classical frontal lobe/executive control tasks is probably not determined by one, but several of these subprocesses: Depending on the theoretical background (and the specific behavioral parameters that are derived from task performance), different studies will sometimes make varying assumptions about the executive control function which is predominantly captured by a given task. In practical terms, this means that researchers are advised to scrutinize the executive control processes that are actually operationalized by using a given task paradigm (see also Tomporowski 2009).

Recently, executive control functions have become a prominent topic in exercise-related cognitive studies (Colcombe and Kramer 2003; Etnier and Chang 2009; McMorris et al. 2011). In particular, there has been a paradigmatic shift in studies investigating the *acute* effects on cognition. While traditional "cognitive-energetic" models concentrated on the acute effects of exercise-induced arousal on elementary information processing capacities (see Sect. 6.2.4.1), there are recent theoretical and empirical considerations which suggest that arousal may also influence executive control, probably via changes in brain DA and NE neurotransmission that modulate neural signaling in those frontal brain networks (Lambourne and Tomporowski 2010; McMorris et al. 2011). Another influential model, the reticular-activating hypofrontality (RAH) model (formerly known as "transient hypofrontality hypothesis": Dietrich and Audiffren 2011), assumes that the need to allocate the limited metabolic (and computational) brain resources to motor control processes triggers a time-limited downregulation of PFC brain activity during acute bouts of exercise. This "hypofrontality" is predicted to interfere specifically with tasks that depend on explicit (i.e., controlled or executive) cognitive processing. Concurrently, there is a strong interest in the *chronic* effects of physical exercise on executive control functions, especially in older populations (Etnier 2009). This interest is fueled by findings from behavioral intervention studies (Kramer et al. 1999; Colcombe and Kramer 2003, but see Etnier and Chang 2009; Smith et al. 2010, for critical comments), as well as an increasing number of structural (e.g., Colcombe et al. 2006; see also Chaps. 17 and 20), and functional neuroimaging studies (e.g., Colcombe et al. 2004; Themanson et al. 2006; see also Chaps. 18 and 19).

The following sections will provide a short review of popular executive control tasks, with a special emphasis on paradigms that were already used in the sports- and exercise-related literature (for comprehensive reviews of the general test literature, see Lezak et al. 2004; Strauss et al. 2006). We will concentrate on two of those executive control functions which are most frequently discussed: *set shifting* (or *cognitive flexibility*) and *inhibition*. As exercise-related applications for many of these tasks are discussed elsewhere in this book, we will mainly concentrate on general descriptions of some prototypical task formats.

6.2.5.1 Set Shifting and Cognitive Flexibility

A basic aspect of goal-directed behavior is the ability to establish and maintain task sets, that is, internal representations of rules or behavioral schemata that associate specific stimuli (or stimulus categories) with specific response options (Robbins 2007). While the ability to establish and maintain task sets is important (especially in the face of distracting stimuli), situational changes or the confrontation with multitasking situations often makes it necessary to adapt behavioral strategies according to modified situational demands, or switch between different goals. Neuropsychological data suggest that the frontal lobe and connected basal ganglia circuits are critical for accomplishing this flexibility (Robbins 2007).

Probably, the *Wisconsin Card Sorting Test* (WCST: Grant and Berg 1948), which has already been used to measure exercise-induced effects in a number of studies (e.g., Dietrich and Sparling 2004; Smiley-Oyen et al. 2008; Del Giorno et al. 2010), is the neuropsychological task that has been most closely linked to frontal lobe function (Etnier and Chang 2009; Jurado and Rosselli 2007). In this task, four stimulus cards are presented as target stimuli. These cards differ from one another on three stimulus attributes (see Fig. 6.2): (a) *number of stimuli* (1, 2, 3, or 4), (b) *color* (red, yellow, green, or blue), and (c) *shape* (cross, triangle, star, or square). Participants receive a second set of cards that show different combinations of the three stimulus dimensions (e.g., one blue square, three green triangles) and are instructed to assign these probe cards to the target stimulus card that shows the best match with regard to a critical stimulus attribute (which may be same shape, same number, or same color). Critically, the relevant attribute is not known in advance but must be inferred from "right" or "wrong" feedback that the experimenter gives after each sorting attempt. Once the correct stimulus dimension is discovered, this sorting rule (or task set) has to be maintained until the experimenter switches the relevant stimulus dimension (e.g., color → number), which is done without an explicit warning. From this point, subjects receive negative feedback for applying the previously established sorting rule. To adapt to the changed feedback contingencies, and avoid perseverative responding, subjects have to inhibit the established task set and use the feedback to switch to the correct task set.

The complex task structure of the WCST has certain drawbacks with regard to the functional interpretation of task performance. While the ability to shift to the relevant task set is clearly relevant, the task compounds this cognitive process with an additional learning component, as the correct stimulus–response mapping has to be inferred from feedback (Robbins 2007). Meanwhile, there are task paradigms where such learning aspects play a more limited role. A classic example is the *Trail-Making Test Part B* (TMT-B; Fig. 6.1), where subjects have to connect circles containing

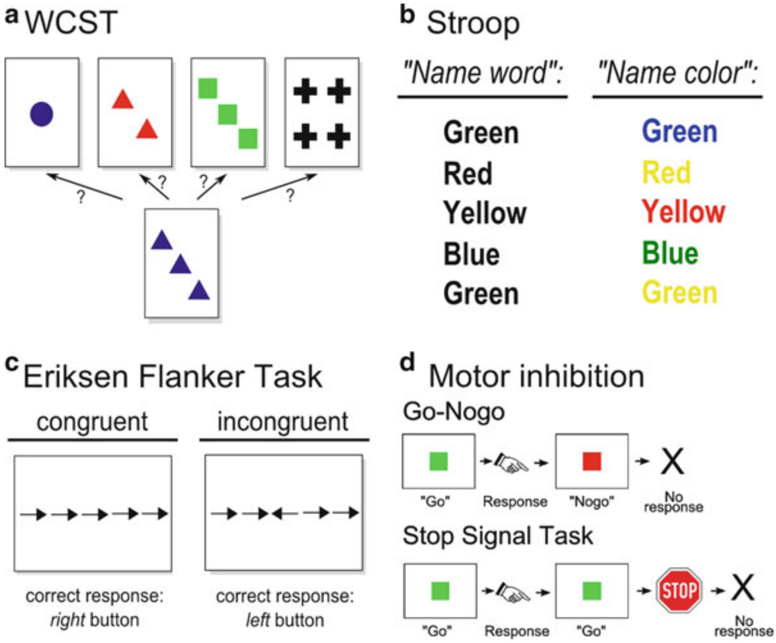

Fig. 6.2 Examples for executive control function tasks. Schematic description of task characteristics. See text for details. *WCST* Wisconsin Card Sorting Test

letters or numbers in alphabetical and numerical order, but in an alternating fashion (i.e., 1—A—2—B—3—C…). This means that the active task set must be continuously switched from letters to numbers, and back again. Another variant are *task-switching paradigms* (Monsell 2003), which have gained popularity in recent exercise-related studies (e.g., Coles and Tomporowski 2008; Kramer et al. 1999), including event-related potential (ERP) neuroimaging studies (e.g., Themanson et al. 2006; for further details, see also Chap. 18). Subjects are trained to discriminate stimuli (e.g., letter–number pairs, such as *5F*) with regard to a specific stimulus attribute, but critically, there are alternative (usually two) response criteria that are related to different stimulus features (e.g., "*Criterion A*: Is the number odd or even?" versus "*Criterion B*: Is the letter a consonant or vowel?"). Behaviorally, this alternation between task sets is associated with a slowing of reaction times (and higher error rates), so-called switch costs, which is usually thought to reflect a rapid task set reconfiguration by a controlling process. Thus, smaller switch costs can be interpreted as an indicator for an increased efficiency of cognitive control.

6.2.5.2 Inhibition

The concept of inhibitory functions refers to psychological processes that provide *active* suppression of other psychological processes, ranging from the sensory and attentional processing of incoming stimuli, to internal (cognitive and affective) states, and to the execution of motor programs (Gazzaley and D'Esposito 2007, but see Aron 2007, for a critical view). Inhibitory functions have been implicated in various psychological tests, including WCST or task-switching tasks (McMorris et al. 2011; Aron 2007; Miyake et al. 2000; Etnier and Chang 2009), but there is a number of prototypical task formats that will be reviewed in the following section.

The *Stroop Color Word Interference Test* is probably the most classic measure of inhibition. While there are many different variants (reviewed by Lezak et al. 2004), the typical paradigm consists of at least two task conditions (see Fig. 6.2). In the control condition, a list of color words (e.g., red, blue, green, yellow) is presented (typically in neutral black ink), and subjects are instructed to read this word content as fast as possible. In the target condition, the *word content* differs systematically from the *printing color* (e.g., red printed in yellow). Critically, subjects are instructed to name the print color as fast as possible, while inhibiting the prepotent tendency to read the incongruent word content. Typically, this interference between color and word content slows response times and increases error probability. Accordingly, a high degree of interference, as indexed by the differences in speed and error rates between target and control condition(s), is interpreted as a behavioral indicator of inhibitory dysfunction.

Similar task demands can be found in *flanker task paradigms* (Eriksen and Eriksen 1974). Subjects are instructed to make a discriminative response to a stimulus that appears in the center of the screen, for example, the direction of an arrowhead pointing to either the left or the right (e.g., Colcombe et al. 2004; Themanson et al. 2008; see Fig. 6.2). Critically, the stimulus is surrounded by distractor stimuli (*flankers*) that can be either response-congruent to the target stimulus (e.g., →→→→→) or response-incongruent (e.g., →→←→→). Thus, attention must be focused on the target stimulus (and corresponding) response option, while inhibiting the processing of the flanker stimuli. Similar to the Stroop paradigm, this conflict typically slows down reaction times and/or increases the error probability for incongruent as compared to congruent trials. Flanker tasks are quite popular of the general functional neuroimaging literature, and there are already several neuroimaging applications in exercise-related studies, including fMRI (Colcombe et al. 2004) and especially event-related-potential (ERP) studies (e.g., Themanson et al. 2008; see also Chap. 18).

Finally, many neuroscientific studies use *go/nogo* and *stop signal tasks* (Fig. 6.2) to measure the active suppression of motor responses (Aron 2007; Robbins 2007). In go/nogo paradigms, subjects have to respond as fast as possible to one class of stimuli ("go" trials), while withdrawing to initiate a response to another class of stimuli ("nogo" trials). Typically, the number of go trials exceeds the number of "nogo" trials in order to establish a prepotent response tendency that has to be inhibited in the "nogo" trials: Thus, the probability of commission errors (i.e., motor responses in "nogo" trials) is a key dependent variable. In contrast, during stop signal tasks, subjects have to react to go stimuli, but in a fraction of trials, a stop signal is presented at a variable time point after the presentation of the go stimuli that signals the need to suppress an already-initiated motor response. If the stop signal appears shortly after the go signal, inhibition is likely to be successful, but if the stop signal appears immediately before the execution of the go response, inhibition will probably fail. By varying this delay systematically, it is possible to infer the minimum time that is typically required to suppress the motor response successfully (so-called stop signal reaction time). Motor inhibition tasks are still rarely used in exercise-related studies: While there is still little evidence for behavioral effects in go/nogo tasks (Smiley-Oyen et al. 2008), there are some positive findings from behavioral studies using stop signal tasks (e.g., Kramer et al. 1999). This may justify further applications, especially in the context of functional neuroimaging, where go/no go and stop signal tasks are frequently used (for a recent meta-analysis, see: Swick et al. 2011). In fact, an initial EEG application of a go/nogo paradigm in the context of acute physical exercise is available (Kamijo et al. 2004).

6.2.6 Global Cognitive Function

Another variable that is potentially relevant for exercise-related research is global cognitive functioning. In a broader sense, this category encompasses a variety of test instruments which aim to provide a general indicator for the cognitive functioning level of an individual, including neuropsychological test batteries (which combine a range of domain specific subtests, e.g., for memory, attention, language), dementia screening inventories, and, most notably, intelligence tests (Strauss et al. 2006).

There are several intelligence tests available, for example, the *WAIS* (Wechsler 2008), or the *Kaufman Brief Test of Intelligence* (Kaufman and Kaufman 1990). These different instruments are based on different theoretical ideas about the underlying structure of intelligence (e.g., the number and nature of measured intelligence factors) that we will not discuss in detail (for a short overview, see Strauss et al. 2006). A recurring theme in intelligence theory and testing is the distinction between *fluid intelligence*, *which* is strongly related to analytic abilities (e.g., problem solving and reasoning) that afford the competency to find new solutions for unknown task situations, and *crystallized intelligence*, which relates to culturally acquired abilities, such as vocabulary, and semantic knowledge. Usually, both aspects are correlated, and as crystallized intelligence measures appear relatively resilient against aging and diseases (as compared to fluid intelligence), neuropsychologists often use these scores to derive an estimate for premorbid global cognitive function, which is especially relevant for assessments in clinical populations. Notably, these estimations are sometimes not directly based on intelligence tests (e.g., the *WAIS Vocabulary* subtest) but inferred from academic achievement tests, such as the *National Adult Reading Test* (Lezak et al. 2004; Strauss et al. 2006).

Turning to exercise-related studies, there are several reasons for using global cognitive measures: First of all, it is generally possible to use these scores as dependent variables, for example, to test whether physical exercise shows any acute (Dietrich and Sparling 2004) or chronic (e.g., Aberg et al. 2009) associations with IQ measures. Meanwhile, such global measures may lack sensitivity to detect subtle cognitive changes (especially crystallized intelligence measures which, as discussed above, are thought to be rather insensitive to changes in brain physiology). Therefore, some authors prefer the assessment of specific cognitive functions, for example, executive control (e.g., Tomporowski et al. 2008). In fact, there seems to be a substantial overlap between executive control and fluid intelligence tasks (Jurado and Rosselli 2007; Strauss et al. 2006).

Meanwhile, there are other methodological considerations: Many of the above-mentioned tests (e.g., learning and memory tasks, such as the RAVLT) show correlations with education and intelligence scores (Strauss et al. 2006): This means that there may be a need to control this factor as a potential covariate, especially in the context of cross-sectional comparisons between groups (e.g., individuals with varying fitness levels) which may systematically differ regarding this background variable.

On the other hand, global cognitive measures may be relevant as a potential moderator variable for the influence of physical exercise on specific cognitive functions: For example, IQ measures are often discussed as an indicator for individual "cognitive reserve" capacities, which are thought to protect against (or at least delay) the detrimental effects of brain insults, such as neurodegenerative processes (Stern 2009). Thus, subjects with higher levels of cognitive ability may be more proficient in developing strategies that help them cope with adverse conditions. On the other hand, as these subjects already perform closer to ceiling level, they may have fewer opportunities to draw additional profit from beneficial interventions (Etnier et al. 2006; Etnier 2009). Consistent with the latter idea, Sibley and Beilock (2007) reported a beneficial effect of acute exercise on a working memory span task, but only for those subjects who showed a low baseline performance in this task.

6.2.7 Caveats and Trends

In recent years, the methodological approaches which are used to investigate the cognitive effects of physical exercise have experienced substantial refinements, and the ongoing development of task paradigms, especially in the field of cognitive neuroscience, will probably result in further improvements.

On the other hand, there are still some practical challenges that need to be considered in study design. A prominent aspect is the timescale of the measured cognitive effects. From a methodological perspective, cognitive assessments *during* the execution of acute exercise bouts are probably associated with the most distinct practical obstacles: For example, it may be necessary to adapt the whole test apparatus (e.g., stimulus display, response buttons) to the situational demands of the exercise regimen. Meanwhile, the motor control requirements of acute physical exercise may still interfere with the parallel execution of a psychological task (i.e., tax divided attention by inducing an implicit dual-task situation; Sect. 6.2.4.2). Notably, this detrimental effect may cease with increasing practice, given that the execution of one (or both) tasks becomes automatic: This could explain observations from a recent meta-analysis (Lambourne and Tomporowski 2010), which indicated that cognitive performance measures show a slight decline during the first 20 min, but not in later phases of acute exercise treatments, while post-exercise measurements even show improvements (which may reflect a carryover of exercise-induced arousal increases into the immediate post-exercise phase). This suggests that the observed behavioral outcome will be influenced by both task selection and type of exercise intervention (Lambourne and Tomporowski 2010).

6.3 Affective Functions

Affective responses to physical exercise have been investigated in a large number of scientific studies. Beyond such phenomena as the runner's high (i.e., a state of euphoria while running), which are relevant only for a minority of athletes, the specific conditions that make physical exercise bouts pleasurable (or aversive) are also important from a public health point of view. For instance, interventions that support the motivation to engage in physical activity may help reduce the prevalence of sedentary lifestyles in Western industrial societies, and the negative health consequences associated with them (Ekkekakis et al. 2005b). In fact, mood enhancement is reported as a result of both acute (Reed and Ones 2006) and chronic (Reed and Buck 2009) exercise, and there are studies that indicate that the initial affective response to a moderate exercise bout predicts regular participation in exercise interventions (Williams et al. 2008). Moreover, the affective impact of physical exercise is also relevant from a clinical perspective, since an increasing number of studies confirm that moderate physical exercise has a beneficial effect on clinical symptoms of anxiety (Wipfli et al. 2008) and depression (Bartholomew and Ciccolo 2008).

This section will review affect-related measurement techniques that are potentially relevant for exercise-related studies. After providing a short outline of important affective phenomena, and relevant psychological theories of affective functions, we will present a number of methodological approaches which are commonly used to operationalize affect. In practice, affective reactions are predominantly measured by asking participants for their subjective affective experiences ("feelings"): Accordingly, affect-related rating scales and questionnaires will play a prominent role in this review. Meanwhile, affective states are not restricted to subjective experience, but can include bodily, motivational, and behavioral responses. Therefore, we provide a brief overview of psychophysiological and behavioral assessment techniques which are commonly used in affective neuroscience. The discussion will conclude with comments on methodological caveats and future prospects.

6.3.1 General Background

Affect is a psychological concept with several related meanings. In general, affects are feeling states that can be characterized as pleasant or unpleasant (i.e., positive or negative) and reflect the subjective perception of what happens in the organism (Parkinson et al. 1996; Gray and Watson 2007). Notably, the term "affect" is used to refer to a variety of affect-related phenomena, for example mood, emotion, temperament, preference, or attitude (Gray and Watson 2007; Smith and Crabbe 2000; Scherer and Peper 2001).

While these affect-related constructs are interrelated, they can be differentiated by specific characteristics, such as intensity, duration, and rapidity of response patterns (Scherer and Peper 2001; Davidson 1998). For instance, *mood* refers to a prolonged affective feeling of an individual that often develops slowly, does not necessarily depend on a specific antecedent event (or may cumulate over several events, respectively), and typically lasts much longer (minutes, hours, or days) than *emotions*, which are acute, intense responses that are triggered by, and time-locked to, specific antecedent events. By contrast, *temperament* and *affect-related personality traits* (e.g., anxiousness, neuroticism) do not describe an immediate affective state, but refer to a stable disposition (or vulnerability) to experience specific emotional and mood states, which is assumed to vary between individuals (e.g., anxious people are more likely to react with anxiety than others). We emphasize these conceptual differences, because it was suggested that the interchangeable use of the term "affect" has been a steady cause of confusion, both in the general (Scherer and Peper 2001) and exercise-related affect literature (Smith and Crabbe 2000).

During the last decades, a number of theories discussed the relationship between exercise and affect. Many of the earlier models proposed that exercise modulates affect by influencing basic physiological mechanisms, such as monoamine or endorphin neurotransmission (Daley 2002), but made a few assumptions about the brain structures and psychological processes that are modulated by these physiological changes. Inspired by theoretical advances in affective neuroscience, recent accounts have started to formulate more specific predictions, and akin to the exercise-related cognitive literature, the regulatory functions of the frontal lobes often play a prominent role in these models (see also Chap. 21): For example, the *dual-mode theory* (DMT) (Ekkekakis et al. 2005b) assumes that exercise-induced affect changes result from evolutionarily adaptive signaling pathways which show a hierarchical organization, with fast and automatic subcortical mechanisms that are regulated by slower cognitive processes on the cortical (e.g., frontal) level. The key aspect of DMT is that cognitive appraisals influence affective processing in low, moderate, and—most importantly—heavy physical activity, which means that the same exercise intensity can cause different affective reactions, depending on the individual cognitive appraisal. Only during severe exercise, aversive bodily signals become overwhelming, and bypass "top-down" cognitive regulation to signal immediate threat to health or survival. Yet, the DMT suggests that heavy and severe exercise may also trigger opponent (possibly: opioidergic) processes with a positive valence that counteract these aversive reactions, which could explain affective rebound phenomena (i.e., a reversal from displeasure to pleasure) immediately after termination of severe exercise bouts. A different account is provided by the *reticular-activating hypofrontality* model (Dietrich and Audiffren 2011): This model proposes that transient hypofrontality effects during the course of intense physical exercise mediate anxiolytic and antidepressant effect by changing the functional balance between the DLPFC and VMPFC, which is known to be implicated in mood disorders (Elliott et al. 2011).

6.3.2 Subjective Measures

The predominant approach to measure affective responses in humans is the assessment of their subjective affective experience (Bradley and Lang 2007). As this subjective experience is only accessible to introspection, individuals have to self-report evaluations of their subjective feelings, usually by rating the appropriateness of word labels that characterize emotional states (Gray and Watson 2007). In exercise-related studies, such ratings are typically used to assess exercise-induced *mood* changes. A short overview of affective self-report instruments that are frequently used in exercise-related studies is provided in Table 6.2: Since there are general overviews available (e.g., Reed and Ones 2006; Reed and Buck 2009; Ekkekakis 2008; see also: Ekkekakis and Petruzzello 1999), we will focus on a selection of popular measures.

As pointed out in previous reviews (e.g., Ekkekakis 2008; Bradley and Lang 2007; Gray and Watson 2007), the available self-report instruments make varying theoretical assumptions about the nature and organization of the affective states that they intend to measure (for a comprehensive review of neuropsychological theories of emotion, see Scherer and Peper 2001). We will broadly distinguish *dimensional* affect measures (e.g., for the positive or negative hedonic valence, or for the arousal level experienced during an affective state), and instruments that focus on *discrete emotions* (e.g., anxiety, fear, anger). Within these categories, we will further differentiate *general* measures (that were developed outside the realm of sports sciences) and *exercise-specific* measures.

6.3.2.1 Dimensional Measures

Dimensional models of affect assume that emotional states vary with regard to general common attributes which are conceptualized as a continuum, such as valence (i.e., the hedonic value, ranging from unpleasant to pleasant), arousal (ranging from low to high), or positive and negative affect (Gray and Watson 2007; Bradley and Lang 2007). Some models suggest that the subjective perception of these affect dimensions reflects the functional organization of underlying motivational systems on the brain level, e.g., in terms of approach/avoidance or appetitive/defensive systems (Davidson 1998; Bradley and Lang 2007).

Typically, these affect dimensions are measured with multi-item questionnaires, such as the *Positive and Negative Affect Scale* (PANAS: Watson et al. 1988). The PANAS contains ten positive affect-related adjectives (e.g., proud, enthusiastic) and ten negative adjectives (e.g., jittery, distressed) to measure positive affect and negative affect dimensions, respectively. Participants rate each adjective according to what they were currently feeling from 1 (*not at all—slightly*) to 5 (*extremely*).

Table 6.2 Affective self-report measures and exercise-related applications

Author	N	Sex	Exercise mode	Exercise duration	Neuronal measure	Questionnaire
Barnes et al. (2010)	30	MI	Cycling	30 min	None	PANAS, STAI, BDI
Bartholomew et al. (2005)	40	MI	Walking	30 min	None	POMS, SEES
Bixby et al (2001)	27	MI	Cycling	30 min	EEG	PANAS
Boecker et al. (2008)	10	M	Running	115 min	PET	VAMS
Dishman et al. (2010)	36	MI	Cycling	To exhaustion	EEG	POMS
Ekkekakis et al. (1999)	69	MI	Running	30 min	None	AD ACL, STAI
Fumoto et al. (2010)	10	MI	Cycling	15 min	NIRS	POMS
Hall et al. (2010)	30	MI	Running	To exhaustion	EEG	AD ACL
Moraes et al. (2011)	29	NR	Cycling	20 min	EEG (loreta)	POMS, STAI
Oda et al. (1999)	8	M	Aqua aerobics	50 min	EEG	POMS
Petruzzello et al. (2001)	69	MI	Running	30 min	EEG	AD ACL
Schneider et al. (2009a)	101	MI	Cycling	30 min	EEG	FS
Schneider et al. (2009b)	24	MI	Running	21–60 min	EEG	Mood meter
Steptoe et al. (1993)	72	M	Cycling	25 min	none	POMS
Vogt et al. (2010)	18	MI	Walking	45–60 min	EEG	Mood meter
Woo et al. (2009)	16	F	Running	15, 30, 45 min	EEG	POMS

M males, *F* females, *MI* mixed, *NR* not reported

PANAS positive and negative affect schedule, *POMS* profile of mood state, *AD ACL* activation deactivation adjective checklist, *VAMS* visual analogue mood scale, *FS* feeling scale, *SEES* subjective exercise experience scale, *STAI* state-trait anxiety inventory, *BDI* Beck depression inventory, *EEG* electroencephalography, *PET* position emission tomography, *NIRS* near-infrared spectroscopy

The questionnaire is frequently used in exercise and sport psychology (e.g., Barnes et al. 2010), including neuroimaging applications (Bixby et al. 2001).

The *Activation-Deactivation Adjective Checklist* (AD ACL: Thayer 1989) is a self-report measure that contains 20 items. There are five adjectives for each of the four subscales *Energy*, *Tiredness*, *Tension*, and *Calmness*, which represent the high and low poles of two orthogonal and bipolar activation dimensions: *Energetic arousal* (Energy—Tiredness) and *Tense Arousal* (Tension—Calmness). Each item is rated on a 4-point Likert scale (ranging from "1—definitely not feel" to "4—definitely feel"). Although not originally developed for this purpose, it was suggested that the AD ACL can be interpreted in terms of a two-dimensional "affective circumplex" model that represents the similarities and differences between affect states by arranging these states around the perimeter of a circle, with experientially similar states located in close proximity (Gray and Watson 2007; Ekkekakis 2008): The structure of this circumplex can be characterized by two orthogonal bipolar dimensions: valence and arousal (see Ekkekakis et al. 2005a, for a detailed discussion of psychometric properties and exercise-related applications of the AD ACL). In a recent study that examined the dose-dependent effects of different exercise intensities on mood states, resting frontal EEG asymmetry was predictive for affective responses after exercise, as measured by the AD ACL (Hall et al. 2010).

While the above-mentioned tests contain multiple items to measure the intended dimension, there are also less complex instruments. For example, the *affect grid* (Russell et al. 1989), which has also been applied in sport and exercise science (Hardy et al. 2001), uses a single rating in a two-dimensional coordinate space to measure hedonic tone (ranging from unpleasant-pleasant) and arousal (ranging from sleepiness-high arousal). The *Feeling Scale* (Hardy and Rejeski 1989) is a single-item scale that measures valence on a bipolar 11-point scale, ranging from −5 (very bad) to +5 (very good), and has already been used in exercise-related EEG studies (Schneider et al. 2009a). While most of these dimensional rating scales use verbal and numerical anchor descriptors, it should be noted that there are also nonverbal approaches, such as the *Self-Assessment Manikin* (SAM: Lang et al. 2008), which uses cartoon characters to symbolize the referenced feeling states on the three dimensions: valence, arousal, and dominance (for an exercise-related example, see Tian and Smith 2011).

Recently, there have been attempts to develop scales that assess emotional responses in the specific context of exercise and sport psychology, such as the *Exercise-Induced Feeling Inventory* (EFI: Gauvin and Rejeski 1993). The EFI has four subscales of *Positive Engagement*, *Revitalization*, *Tranquility*, and *Physical Exhaustion*. While the instrument has had positive reviews and empirical applications (e.g., Szabo and Bak 1999; Vlachopoulos et al. 1996), it should be noted that the validity of the different subscales has been questioned (Ekkekakis and Petruzzello 1999).

6.3.2.2 Discrete Emotions

A number of emotion theories are based on the idea that there is a number of distinct emotion qualities, or categories, that are not only associated with distinct feeling states, but also with stereotyped response patterns, which are probably hard-wired in specific brain circuits: For example, fear responses are linked with a network including amygdala, hypothalamus, and periaqueductal gray (Panksepp 1988). While there are some prototypical examples, such as the basic emotions *happiness*, *sadness*, *fear*, *anger*, *disgust*, and *surprise*, there is no generally accepted taxonomy for these discrete emotional qualities, and as a consequence, a broad range of alternative scales with varying contents is in practical use.

A questionnaire that is frequently used to show exercise-induced changes in discrete mood states is the *Profile of Mood States* (POMS: McNair et al. 1971). In the long form, the scale contains 65 adjectives, which have to be rated on a 5-point Likert scale. The adjectives are assigned to six subscales, five with a negative content (*tension-anxiety*, *depression-dejection*, *anger-hostility*, *fatigue-inertia*, and *confusion-bewilderment*), and one with a positive content (*vigor-activity*). Meanwhile, please note that some studies (e.g., Woo et al. 2009) also integrate the different subscales to generate a summary "total mood disturbance" score (TMD = [(tension + depression + anger + fatigue + confusion)—vigor]), which in fact means that the POMS is converted into a dimensional, negative valence scale. Studies using the POMS to measure mood changes have been successful in showing that, for instance, *acute* mood changes are beneficial at low exercise intensity levels (Steptoe and Cox 1988). Further, studies have shown that moderate exercise intensities (Davranche et al. 2006) change mood more compared to high intensities (Steptoe et al. 1993), indicating an inverted U-curve relation between exercise intensity and mood. Consistent with the prominent role of the POMS in the sports literature, some exercise-related studies have also used the POMS in neuroimaging studies, for instance, to correlate acute changes in mood and EEG activity (Fumoto et al. 2010; Oda et al. 1999; Vogt et al. 2010). Finally, POMS scores were used in many studies which investigated the chronic effects of exercise in different exercise programs and populations (Reed and Buck 2009).

A practical disadvantage of the POMS is the considerable number of test items: Therefore, there have been attempts to develop shortened versions of the POMS for exercise-related applications (discussed in Leunes and Burger 2000): In some cases, each of the six subscales is reduced to one single item (e.g., Anderson and Brice 2011). A complementary approach is the use of visual analogue scales, such as *Visual Analogue Mood Scales* (VAMS: e.g., Stern et al. 1997), which have already been applied in exercise-related studies (e.g., Bixby et al. 2001): Instead of using multiple items to aggregate ratings for a given affective state, participants are directly asked to rate the current appropriateness of a affective state (e.g., sadness, tension, anger, fear, fatigue) by marking the corresponding position on a continuous horizontal line, with written anchors at either end point to define the possible extremes (e.g., "not at all sad" to "very sad").

While the POMS or VAMS capture a variety of distinct affective states, other measures concentrate on specific affective experiences. A classical example, which may be especially relevant for exercise-related studies in psychiatric populations, is the *Beck Depression Inventory* (BDI: Beck et al. 1961), which aims to measure the severity of depressive mood symptoms with 21 multiple-choice items. Another important example (which is frequently studied in exercise research) is anxiety. A common instrument for the measurement of anxiety is the *State-Trait Anxiety Inventory* (STAI: Spielberger et al. 1970). The STAI contains 40 items in total, using 20 items for trait (e.g., "I lack self-confidence") and 20 items for state (e.g., "I feel upset") anxiety. Within sport and exercise psychology, the *Competitive State Anxiety Inventory* (CSAI: Martens et al. 1990) is frequently used, with a recent development including questions on how often negative feelings occur and whether these feelings have a negative or positive effect on performance (Martinent et al. 2010).

Whereas anxiety is an emotional state for which both general and exercise-specific questionnaires have been developed, the same cannot be said for many other emotion categories. There have been some exercise-specific scales developed for other emotions (e.g., Elbe et al. 2005), but in most cases, researchers have to rely on general affect questionnaires.

6.3.3 Objective Measures

Affective (and especially: emotional) responses are not limited to the subjective experience of an affective feeling, but can include other forms of expression. Although this assumption is implicit to many theories of affect, it is especially emphasized by c*omponential models* of emotion (e.g., Scherer and Peper 2001). These models conceptualize emotions as a complex pattern of responses that unfold dynamically and over multiple modalities. These modalities include *cognitive appraisals* (e.g., subjective evaluations of the significance of an affective event, and the expected ability to cope with these events), *physiological responses* (bodily symptoms: e.g., neuroendocrine responses and autonomic changes), *motivational changes* (action tendencies, in terms of approach, defense, or withdrawal), *motor expressions* (facial and vocal expression), and, of course, *subjective feelings* (emotional experience, as measured by subjective rating scales). In fact, there is a long-standing debate whether subjective emotional feelings may primarily reflect the interoceptive experience of these bodily changes (Scherer and Peper 2001; Bradley and Lang 2007; Kreibig 2010).

Emotion researchers have developed a variety of psychophysiological assessment techniques that are used to derive objective measures for these response modalities, some of which will be introduced in the following section. If possible, we will refer to exercise-related applications (see also Smith and Crabbe 2000; Smith and Cook 2005).

6.3.3.1 Standardized Elicitation of Affective Responses in the Laboratory

Typically, psychophysiological laboratory studies do not observe spontaneous fluctuations of the affective state of study participants, but measure affective responses in standardized settings, for example by presenting stimuli that aim to provoke emotional reactions (e.g., verbal, pictorial, or acoustic stimuli with emotional content), or by instructing participants to imagine emotionally arousing situations (Bradley and Lang 2007). One of the most prevalent approaches is the use of material from the *International Affective Picture System* (IAPS: Lang et al. 2008), a collection of scenic photographs with appetitive, aversive, or neutral contents. For each of these pictures, normative SAM ratings for three affective dimensions (valence, arousal, and dominance) are available, which allows researchers to deliberately select stimuli based on their affective properties. Another popular approach is the presentation of faces with emotional expressions (e.g., anger, fear, disgust), which are usually taken from standardized picture series, such as the classic *Pictures of Facial Affect* set (POFA: Ekman and Friesen 1976).

While the above-mentioned stimulus types mainly have a conditioned affective value (i.e., are learned), it is also possible to use innate, unconditioned stimuli (e.g., painful heat or electroshocks: Bradley and Lang 2007; see also Chap. 7). A related approach that is commonly used in exercise-related studies to induce negative mood states (Hamer et al. 2006) is the performance of cognitively demanding tasks under stressful conditions (e.g., delivering a public speech, mental arithmetic under time pressure).

6.3.3.2 Autonomic Responses

A classical approach to assessing emotional responses on an objective level is the collection of physiological responses, for instance, changes in neuroendocrine, electrodermal, respiratory, cardiovascular, skeletal muscular, or gastrointestinal activity (Bradley and Lang 2007; Gray et al. 2009; Kreibig 2010).

A prominent technique is the observation of electrodermal activity, for example, emotion-induced changes in *galvanic skin resistance* (GSR). GSR shows an exclusive link with sympathetic nervous system activity, because the sympathetic innervations of sweat glands influence electric skin conductance, which can be measured with surface electrodes (Bradley and Lang 2007; for technical details, see Smith and Cook 2005; see also Chap. 7). GSR increases after presentation of affective stimuli were shown to be a good indicator of emotional arousal, although it has to be noted that GSR is not sensitive to emotional valence (i.e., increases for both positive and negative arousing events: Bradley and Lang 2007; Smith and Crabbe 2000). In general, exercise-related applications of GSR measures are rare, and provide mixed results (e.g., Steptoe et al. 1990; Rodrigues et al. 2007). Yet, it must be acknowledged that the acquisition of GSR responses is technically challenging, especially during or immediately after acute exercise bouts, where increased sweating reduces skin resistance tonically (although it may still be possible to detect phasic responses: Smith and Cook 2005).

Moreover, there is a variety of cardiovascular response modalities, such as *blood pressure* (see also Chap. 7) and *heart rate* (HR). For example, emotional stimuli have been shown to modulate the temporal pattern of HR decelerations and accelerations that are typically triggered by stimulus processing (see review in Bradley and Lang 2007). There are a number of exercise-related applications, primarily studies that examined cardiovascular responses to psychological (e.g., public speaking, mental arithmetics) or physical stressors (e.g., painful stimulation). While there is evidence that acute bouts of exercise reduce blood pressure responses to psychosocial stressors (at least for durations >30 min at 50% $\dot{V}O_2$max: Hamer et al. 2006), recent meta-analytic analyses (Jackson and Dishman 2006) have questioned the assumption that cardiorespiratory fitness mitigates cardiovascular responses to psychosocial stressors, suggesting that many of the positive findings in the available literature may be explainable by methodological flaws. Another relevant parameter is *heart rate variability* (HRV), i.e., the variability of beat-to-beat intervals, which reflects the relative sympathetic-vagal balance of an organism (Malik 1996). While the HRV is strongly driven by respiratory rhythms (respiratory sinus arrhythmia), emotional arousal can modulate HRV parameters (Kreibig 2010; Appelhans and Luecken 2006), and there are some exercise-related studies that used HRV to obtain unobtrusive measures of pre-competitive arousal in athletes (Murray and Raedeke 2008; Laborde et al. 2011). Moreover, there is accumulating evidence that certain psychiatric populations (e.g., panic disorder patients) show trait-like HRV reductions (i.e., a reduced ability to adapt affective responses to the situational context) that may reflect a more general impairment of emotional regulation processes, possibly via PFC mechanisms: Thus, low HRF has been discussed as a potential biomarker, or even endophenotype, for a broad range of dysfunctions in affective (but also physical and cognitive) regulation (Thayer and Lane 2009). Again, it is tempting to speculate whether HRV changes might qualify as an objective indicator for the affective benefits of regular physical exercise in these patient populations.

6.3.3.3 Motor and Motivational Responses

Obviously, the most salient motor expressions of affect are emotional face expressions. In fact, the unique pattern of facial muscle activities that are characteristic for basic emotions (e.g., fear and disgust) provides an important social signal that we use intuitively to make inferences about the current emotional experience of others. There are several observer-based coding systems that aim to formalize this intuitive analysis with standardized coding systems, for example, the *Facial Action Coding System* (FACS: Ekman and Friesen 1978), which decomposes facial expressions into predefined facial movement elements. Additionally, it is possible to measure the underlying activity of specific facial muscles (e.g., the corrugator supercilii, zygomaticus major, and orbicularis oculi muscle) with *facial EMG*, which offers the possibility to detect subtle changes that are not detectable for an observer (Bradley and Lang 2007; Smith and Crabbe 2000). Yet, exercise-related applications are rare (Fillingim et al. 1992), precluding meaningful conclusions for this kind of paradigm.

The acquisition of facial EMG is also relevant for measuring the acoustic startle eyeblink reflex, a defensive reflex that can be used to investigate the motivational state of an individual (Smith and Crabbe 2000; Bradley and Lang 2007). In typical experimental procedures, this reflex is tested by presenting loud bursts of white noise, and measuring the amplitude and latency of EMG responses from the orbicularis oculi muscles. The intensity of the acoustic startle eyeblink reflex is known to be modulated by the current affective state of an individual, e.g., while viewing positive or aversive IAPS pictures (see Bradley and Lang 2007, for an overview). Theoretically, exercise-induced mood changes may influence the situation-specific appraisal of such affective stimuli, and, thus, the *affective modulation of the startle response*. Actually, there have been some applications in the context of acute exercise studies (e.g., Smith and O'Connor 2003; see also Smith and Cook 2005), but to date, no reliable changes in affective startle modulation were observed, making this paradigm a less promising candidate for future studies, at least in the context of acute exercise studies. Meanwhile, clinical studies indicate that patients with mood disturbances show a dysfunctional affective modulation of startle responses (e.g., blunted affective modulation in depressives: Mneimne et al. 2008). Therefore, it is interesting to speculate whether this kind of paradigm could provide a biomarker for the mood-enhancing effects of regular physical exercise in these patient populations.

6.3.3.4 Modulation of Cognitive Processes by Affect

In recent years, considerable progress has been made to create experimental settings that assess the effects of affective states on cognitive processing (see Elliott et al. 2011, for review). In these "affective cognition" paradigms, affective stimuli are presented in the context of a primary cognitive task. It is implicitly assumed that the motivational significance of affective stimuli influences cognitive processing by automatically guiding attentional resources toward (or away from) the emotionally significant stimuli. Depending on the specific task context, these attentional biases can either facilitate, or interfere with cognitive performance, which is reflected by a modulation of response speed or accuracy for affective, as compared to neutral stimuli.

One relevant example is the *Emotional Stroop* task, where participants have to name the print color of emotional and neutral words (analogous to traditional Stroop paradigms). Another typical variant is the *attentional (or "dot") probe paradigm*. Here, participants briefly view pairs of stimuli which appear in different spatial locations and have different affective value (e.g., left: positive; right: neutral). Afterward, a probe stimulus appears at one of the two stimulus locations, and participants are instructed to respond to this stimulus as fast as possible (e.g., discriminate: Is the letter a *b* or a *p*?). Assuming that the affective stimuli attract (or divert) the attentional focus, response latencies for probes that replace emotional and neutral stimuli, respectively, should differ, i.e., show an *attentional bias*. Still, there are few applications in exercise-related studies: While Barnes et al. (2010) observed no attentional bias effects *after* an acute bout of moderate exercise, a recent study by Tian and Smith (2011) suggests that modulating effects may indeed be present, at least *during* moderate exercise. They predicted that moderate exercise would induce a positive affective state that induces an attentional bias toward pleasant faces, but away from unpleasant faces, while high intensity exercise was expected to induce a negative affect state that would have the opposite effect on attentional bias scores. Although no effects were observed during high intensity exercise, the predicted bias changes emerged during the moderate exercise condition, which may reflect a positive affective shift during this condition. Nevertheless, further research is needed to corroborate these initial findings.

6.3.4 Caveats and Trends

Given the various distinctions between affect-related constructs (e.g., emotion, mood, temperament) and the different theoretical models of affective function, this section could give only a rather selective review of general methodological avenues. To complete this general state-of-the-art review of psychological affect measures, and their application in exercise-related studies, a number of caveats and possible trends should be considered.

Exercise-related studies predominantly use self-report rating scales that are either based on dimensional or discrete (i.e., categorical) affect models, and ongoing debate ensues regarding the most adequate measurement approach. Ekkekakis (2008) notes that there is an inherent risk in using scales for discrete emotional states, as these scales may only capture specific kinds of affective reaction, while potentially missing other affective reactions that may also be sensitive to the influence of physical exercise. This does not generally question the assessment of specific affective states (e.g., anxiety, euphoria) in exercise-related studies, but Ekkekakis (2008) recommends clarification of the rationale for the selection of specific affective states in exercise studies. In general, this implies that scale selection should be guided by a specific idea about the nature of the expected affective changes: For instance, should "feeling better" be defined as anxiety *reduction* or positive mood *induction* (Yeung 1996; Reed and Ones 2006; Wipfli et al. 2008)? These two forms of affective change do not necessarily coincide (Barnes et al. 2010).

In addition, it is disputable whether a change of affect should be measured by comparing pre- and posttest ratings on an *absolute* scale, or by using a *comparative* scale, where subjects provide a *post hoc* evaluation of changes from pre- to posttest. Which of these two strategies represents a better description of the subjects' response is a matter of debate (see: Carlsson 1983 for review). There is evidence that retrospective evaluations of affective states may be vulnerable to memory bias effects (Anderson and Brice 2011).

This draws attention to another crucial study design issue: *When* and *how often* should we test the affective state? This is important because affect responses may not increase or decrease linearly over time, and therefore, *post*-exercise assessments do not necessarily reflect the mood state *during* exercise: For instance, the observation of positive affect after exercise may reflect a post-exercise rebound after experiencing acute mood decline during exercise (Ekkekakis et al. 2005b; Reed and Ones 2006). A simple but costly strategy is to assess affect during exercise and relate it to baseline before and after exercise.

Here we are confronted with another obstacle: Many of the above-mentioned questionnaires use multiple items to measure the affective variable of interest. While this approach can increase the reliability of the measurement, multiple-item questionnaires naturally carry the risk of test fatigue, especially in situations where the assessment is repeated at multiple time points, for instance, over the course of an acute exercise bout. In this situation, single-item scales may provide the only viable alternative. Yet, it should be kept in mind that single-item scales may be more prone to the influences of measurement errors (Leunes and Burger 2000).

Another risk of repeated affect measurements over multiple time points is the unintended generation of demand and social desirability effects in participants who understand the role of emotions in the given study and therefore may alter their reported affective response, voluntarily or involuntarily (Anderson and Brice 2011; for a detailed discussion of expectancy effects, see also Morgan 1997). This may be especially salient for single-item rating scales where the measures construct can already be inferred from the presented scale description.

To avoid (or at least: reduce) this kind of artifacts, it would be a desirable strategy to run objective, unobtrusive affect measures (Smith and Cook 2005). Still, there are comparably few applications of these methodologies in exercise psychology, and this may (at least to some extend) be explained by the fact that these measurement approaches can also entail important obstacles. In general, the collection of psychophysiological data is often associated with considerable technical and personal efforts, which may not always be affordable in practice. Moreover, the specificity of the measured responses is often debatable: For example, some parameters (e.g., SCR, HR) are only sensitive to emotional *arousal*, but not to emotional *valence* (Smith and Crabbe 2000; Bradley and Lang 2007; Scherer and Peper 2001). Moreover, these responses are not specific to emotion, but can also reflect nonemotional mechanisms, for example, orienting responses or attentional effort (Smith and Crabbe 2000; Smith and Cook 2005). In particular, studies examining affective responses *during* acute exercise are confronted with the problem that physical activity itself induces physiological responses (e.g., increased heart rate, muscular tension, sweating) which can overshadow the subtle changes triggered by affective reactions (Bradley and Lang 2007; Smith and Cook 2005). This problem is less compelling for studies that investigate the chronic effects of regular exercise during rest. Yet, it should be considered that changes in physical fitness may influence physiological responsiveness in general (especially for the cardiovascular system), which could also have an impact on affect-related responses in these modalities. Moreover, it should be noted that the covariation between subjective and objective affect measures is far from perfect. In general, a synchronized co-activation of the different response levels should primarily be expected during acute emotions, and even here, we can often not expect strong correlations, because the specific response patterns (e.g., timing, and intensity) for the different affect components can show substantial variation, depending on factors such as stimulus characteristics, emotional state, and interindividual differences (Scherer and Peper 2001). Therefore, it seems advisable not to *replace* subjective ratings by objective measures, but to *combine* the different observation levels to achieve multivariate measurements (Bradley and Lang 2007; Scherer and Peper 2001), which can be analyzed for emotion-specific consistencies in response patterns (e.g., Stephens et al. 2010).

Another aspect that should be considered is the possibility that the relationship between exercise and affect may not be uniform, but moderated by individual background characteristics, for example personality traits (e.g., anxiousness, extraversion, sensation seeking), attitudes (e.g., self-efficacy), or preferences (Ekkekakis and Petruzzello 1999). As personality traits describe the fact that individuals can generally show a stronger (of weaker) tendency to react with certain affective states, and it is plausible that these dispositions can moderate the affective effects of physical exercise. For instance, exercise effects on mood differ depending on whether specific preferences have been met (Brümmer et al. 2011; Schneider et al. 2009b; see also Chap. 21). Moreover, the anxiolytic effect of acute exercise may be more significant in participants with higher trait anxiety levels (e.g., Barnes et al. 2010). It is too early to provide taxonomies of different affective styles and personality variables that moderate the exercise–emotion relationship, but recent efforts are promising (Rhodes and Smith 2006; Schneider et al. 2009a).

Finally, the exercise–affect relation is often examined in isolation, as is the exercise–cognition relation. However, it is evident from previous psychological research that affect and cognition are interrelated, and therefore, further gains are expected in a more complex exercise–emotion–cognition relation. Some recent studies have examined these more complex associations, strengthening the complex relationship empirically. For instance, a recent study (Tomporowski and Ganio 2006) found that an acute bout of aerobic exercise not only influenced subsequent executive control in a task-switching paradigm, but concurrently changed the emotional reactivity to the demands of tasks. While participants generally reported that they experienced a stronger mental demand (as measured via the *NASA Task Load Index*) during the processing of a short-term memory task, as compared to task processing in a task-switching paradigm, both tasks were perceived as less frustrating after exercise, as compared to after rest (Tomporowski and Ganio 2006).

6.4 General Considerations

This chapter aimed to give an illustrative overview of psychological assessment techniques, with a special emphasis on functional domains that appear to be most relevant for current exercise research. There are many additional tests and measurement techniques that could be equally relevant but were not discussed in detail. For a more detailed picture, we have to refer to supplemental literature. For example, Lezak et al. (2004) and Strauss et al. (2006) provide excellent reviews of standardized test procedures for the neuropsychological assessment of cognitive functions, while Coan and Allen (2007) and Bradley and Lang (2007) present a broad variety of measurement techniques that are important in emotion research. This chapter will conclude with general considerations about practical issues that may be relevant for the selection of psychological assessment techniques in exercise-related research, especially for future neuroimaging studies.

6.4.1 Which Task Is Appropriate?

Given the multitude of psychological test instruments that are available, the selection of the most appropriate task for a specific research question can be challenging. There are no “gold standards”, and the available exercise-related studies use a broad range of different instruments to operationalize cognitive and affective functions. Accordingly, recent meta-analyses point out that this diversity complicates the qualitative and quantitative synthesis of the available psychological data (Colcombe and Kramer 2003; Tomporowski 2009; Lambourne and Tomporowski 2010).

From a methodological point of view, task selection should be based on theoretical assumptions about the psychological constructs that have to be measured, and thus, a critical question is whether the utilized instruments sufficiently capture the intended constructs, i.e., show sufficient *construct validity* (Ekkekakis 2008; Tomporowski 2009). As we have illustrated, contemporary psychology has fractionated the traditional psychological domains, such as “memory,” “attention,” and “emotion,” into a variety of specialized functional components, which multiplies the possible number of mechanisms that could be targeted by the modulating effects of physical exercise. In practical terms, this implies that global hypotheses, such as “physical exercise influences memory”, may often be too unspecific, and researchers must be aware that the specific tasks they choose to operationalize psychological function will probably only assess some relevant aspects of a targeted construct, but possibly miss other aspects. For example, traditional memory tests (e.g., the RAVLT) assess the influence of physical activity on *declarative* memory functions but allow no inferences about *nondeclarative* memory (in fact, physical exercise may even have opposite effects: Eich and Metcalfe 2009). Moreover, there is probably no single test instrument that can provide a comprehensive assessment of executive control (Etnier and Chang 2009). A similar situation can be found for the assessment of affective responses, where there have been criticisms that scales for discrete emotions may only sample specific aspects of affective experience (Ekkekakis 2008): An illustrative example is the POMS, where five out of six scales describe negative mood states, while only “vigor” can be interpreted in terms of positive mood states (Anderson and Brice 2011).

Yet, it must be acknowledged that our theoretical advances in conceptualizing cognitive and emotional functions are not necessarily reflected by the tasks that are available for their practical assessment, i.e., there is often no one-by-one correspondence between psychological constructs and behavioral tasks: For example, many of the above-mentioned cognitive tests, such as TMT, WCST, Stroop, and RAVLT, predate the development of modern cognitive theories, and, hence, are not specifically tailored for measuring specific cognitive function.

Probably, the best practical solution to deal with the above-mentioned problems is the application of a broader test battery (e.g., for executive control functions: Miyake et al. 2000; Etnier and Chang 2009), and, especially in the affective domain, the use of multiple, subjective and objective measurement techniques. On the one hand, this approach would allow an exploratory approach in situations where no specific hypotheses about the relevant psychological processes are available. On the other hand, the use of tasks with overlapping functional demands allows us to make comparisons between tasks that draw on similar psychological processes (e.g., inhibition, declarative memory), and should therefore share a vulnerability to exercise-induced effects that modulate the respective processes. Of course, there is often insufficient time for broad batteries, especially in studies that investigate transient acute exercise effects, which may dissipate before the test battery is completed. Thus, a careful, theory-driven selection of tasks that are likely to tap into the psychological process(es) of interest remains a key methodological issue (Etnier and Chang 2009; Strauss et al. 2006).

6.4.2 The Relationship Between Brain and Behavior

In this chapter, cognitive and emotional test instruments were implicitly discussed as behavioral markers for underlying changes on the brain level. Actually, there is a long tradition in clinical neuropsychology to use psychological tests as localizer tasks, that is, to make inferences about *where* the brain shows functional alterations. In exercise sciences, there are currently two brain regions that seem to be especially relevant for this logic: the frontal lobe and the hippocampus. Actually, the fact that recent neuroimaging studies find exercise-related differences in these brain regions (e.g., see also Chaps. 17 and 19) adds plausibility to this assumption.

Yet, we should always be aware of the alternative possibility that observed behavioral differences are not (or at least not only) mediated by physiological mechanisms, but may also be influenced by nonbiological factors (Spirduso et al. 2008). For example, it has been suggested that the antidepressant effects of exercise are mediated by enhanced feelings of self-efficacy (as a consequence of experiencing mastery over the exercise regimen), or by distracting attention from ongoing ruminations (Barnes et al. 2010; Daley 2002).

6.4.3 Translational Research

While neuroimaging studies of physical exercise in human subjects have gained popularity in recent years (e.g., Colcombe et al. 2004; Themanson et al. 2006; Erickson et al. 2009), many of our current insights into the brain mechanisms of physical exercise were gained in animal studies (Cotman et al. 2007; Etnier 2009; Sect. 1, this volume). An obvious advantage of animal studies is the opportunity to derive direct measurements of brain physiology via invasive techniques, which are usually not available in human studies. Meanwhile, the integration of these different approaches can be challenging, as not only the physiological measurement techniques, but also behavioral paradigms are not always complementary, which can hamper the generalizability of results across species. This lack of complementary testing procedures is most obvious for paradigms that draw on verbal responses (e.g., certain memory tests, verbal IQ measures, and questionnaires for subjective emotional experience), which are naturally not applicable in animal research.

Meanwhile, there are an increasing number of test instruments that have been adapted to both human and animal research (e.g., go/nogo, stop signal task), or were even explicitly designed to maximize cross-species comparability, for example, the *Cambridge Neuropsychological Test Automated Battery* (CANTAB®: Cambridge Cognition, Cambridge, UK). Recent methodological advances in translational neuroscientific research are promising, and it is likely that exercise-related research will profit from future developments in this field.

6.4.4 Transfer from Behavioral to Neuroimaging Studies

Currently, the majority of studies that investigate the psychological effects of physical exercise are still based on behavioral assessments. After establishing a link between exercise and the outcomes of specific psychological tests, it is an obvious idea to use neuroimaging techniques to search for physiological processes that are correlated with these behavioral changes.

Straightforward solutions are possible in situations where behavioral parameters from conventional "paper and pencil" tests can be correlated with parameters of brain function that are assumed to be rather stable, for example, brain structure volumes (Chaddock et al. 2010), resting-state functional connectivity in fMRI data series (Voss et al. 2010), or resting brain regional blood flow (Pereira et al. 2007), because it is possible to collect the psychological tests and physiological measurements at different time points and places (although close temporal proximity between the two measurements generally remains desirable).

The situation is different for functional activation studies, where behavioral task paradigms are used to evoke cognitive or affective processes and observe the corresponding, time-locked brain responses in the neuroimaging data. Here, behavioral assessments and neuroimaging need to be synchronized, and the form of cognitive or affective stimulation has to be adapted to the prerequisites of the imaging technique. While several of the above-mentioned behavioral tasks have been adapted to neuroimaging experiments, and although there are already exercise-related neuroimaging applications for some of these paradigms, for example, for flanker tasks (Colcombe et al. 2004; Themanson et al. 2008), and task-switching paradigms (Themanson et al. 2006), several technical and design issues have to be considered, especially in fMRI experiments. These requirements will often complicate a simple transfer from behavioral to neuroimaging studies.

For example, subject motion during the acquisition of the neuroimaging data is a critical issue, since many of these techniques afford participants to be immobilized as much as possible. This prerequisite does not only limit the acquisition of fMRI data during acute exercise, but also complicate the adaptation of many neuropsychological "paper and pencil" tests, where task performance often depends on oral or complex motor responses (e.g., writing, manual manipulation of objects). Typically, this problem is solved by minimizing the motor requirements of the task, for example, by limiting subject responses to button presses or the manipulation of a joystick. Yet, it has to be kept in mind that such modifications can occasionally alter the specific quality of the task. Motor constraints are also limiting the online assessment of emotional experience. Multi-item questionnaires for subjective emotional experiences, which are prominent in behavioral studies, are generally difficult to implement in the scanner environment. Typically, subjective ratings are restricted to short, unidimensional ratings (e.g., for valence, or arousal). For example, Goldin et al. (2005) asked participants to evaluate emotion intensity continuously by using a rating dial that regulated the height of bar graph.

Functional neuroimaging investigations of affective experience have to cope with additional drawbacks: There is an ongoing discussion whether the explicit instruction to make conscious reflections about the subjective affective experience can influence the pattern of brain activations that are elicited by emotional states (Taylor et al. 2003). Therefore, implicit measurements of affective reactions, for example by the measurement of psychophysiological responses, may provide important supplementary information. While special technical solutions are needed to transfer psychophysiological measurement techniques (e.g., for GSR, HRV, EMG) to the MR environment, they become more and more prevalent in fMRI research (for a comprehensive review, see Gray et al. 2009; see also Chap. 7). Although it must be acknowledged that there are still few exercise-related studies that used these measurement techniques successfully, future studies in this field may profit from these refinements. Another methodology that could be relevant is the use of affective cognition paradigms, which have already been adapted in several fMRI experiments with healthy and psychiatric populations (Elliott et al. 2011). Again, the available behavioral data from exercise-related studies (e.g., Barnes et al. 2010; Tian and Smith 2011) are too scarce (and ambiguous) to formulate clear recommendations.

Another practical problem which should be considered while adapting behavioral tests to an fMRI environment is scan duration: Functional neuroimaging experiments are often much longer than complementary behavioral tests because a large number of observations are needed to derive reliable brain activation patterns. These longer task durations may not always be tolerated by participants, and may also narrow possibilities to measure transient post-exercise effects (which may already dissipate during the experiment).

Finally, functional imaging experiments typically compare brain activations during "active" task conditions with brain activations during "control" task conditions in order to isolate those brain activations that are genuine to the cognitive or affective process of interest, while cancelling out activations due to irrelevant sensory, cognitive, or motor processes. In practice, the search for an appropriate control condition can be a reasonable challenge, especially in situations where the transformation of complex tasks is intended (e.g., the WCST), where several processing steps may need to be fractionated by comparing different "active" and "control" conditions: Therefore, it often seems impracticable to adhere to the original behavioral tasks (Frith et al. 2004). In any case, a thorough understanding of the cognitive (or affective) processes that are assumed to be participating in task completion remains an important prerequisite for designing efficient neuroimaging experiments.

6.5 Conclusion

While the advent of modern neuroimaging technologies has brought fascinating opportunities to gain direct insights into the physiology of the human brain, psychological assessment techniques continue to play an important role, because they provide complementary outcome measures that allow inferences about the functional significance of the neuroimaging data, and because psychological background variables (e.g., global cognitive function, personality traits) may be relevant as potential confounds, or moderator variables. This holds also true for neuroimaging studies that aim to investigate the influence of physical exercise on brain function. While this research field is still developing, there are promising perspectives: For example, the assessment of executive control functions will probably continue to play a prominent role, and there is a growing interest in behavioral tasks that are sensitive to hippocampal memory functions. Meanwhile, the measurement of affective responses is mainly based on subjective affect ratings, with comparably few applications of objective measurement techniques. Future exercise-related studies will probably profit from the ongoing development of advanced behavioral paradigms in cognitive and affective neurosciences. These methodological refinements will help to improve our understanding of the brain mechanisms that mediate the modulating effects of physical exercise on psychological function.

References

Aberg MA, Pedersen NL, Toren K, Svartengren M, Backstrand B, Johnsson T, Cooper-Kuhn CM, Aberg ND, Nilsson M, Kuhn HG (2009) Cardiovascular fitness is associated with cognition in young adulthood. Proc Natl Acad Sci USA 106:20906–20911

Anderson RJ, Brice S (2011) The mood-enhancing benefits of exercise: memory biases augment the effect. Psychol Sport Exerc 12:79–82

Appelhans BM, Luecken LJ (2006) Heart rate variability as an index of regulated emotional responding. Rev Gen Psychol 10:229–240

Aron AR (2007) The neural basis of inhibition in cognitive control. Neuroscientist 13:214–228

Atkinson RC, Shiffrin RM (1968) Human memory: a proposed system and its control processes. In: Spence KW, Spence JT (eds) The psychology of learning and motivation, vol 2. Academic, New York, pp 89–195

Audiffren M (2009) Acute exercise and psychological functions: a cognitive-energetic approach. In: McMorris T, Tomporowski PD, Audiffren M (eds) Exercise and cognitive function. Wiley, Chichester, pp 1–39
Baddeley AD (2003) Working memory: looking back and looking forward. Nat Rev Neurosci 4:829–839
Baddeley AD, Hitch G (1974) Working memory. In: Bower GH (ed) The psychology of learning and motivation: advances in research and theory, vol 8. Academic, New York, pp 47–89
Barnes RT, Coombes SA, Armstrong NB, Higgins TJ, Janelle CM (2010) Evaluating attentional and affective changes following an acute exercise bout using a modified dot-probe protocol. J Sports Sci 28:1065–1076
Bartholomew JB, Ciccolo JT (2008) Exercise, depression and cognition. In: Spirduso W, Poon LW, Chodzko-Zajko W (eds) Exercise and Its mediating effects on cognition. Human Kinetics, Champaign, IL, pp 33–46
Bartholomew JB, Morrison D, Ciccolo JT (2005) Effects of acute exercise on mood and well-being in patients with major depressive disorder. Med Sci Sports Exerc 37:2032–2037
Beck AT, Ward CH, Mendelson M, Mock J, Erbaugh J (1961) An inventory for measuring depression. Arch Gen Psychiatry 4:561–571
Bird CM, Burgess N (2008) The hippocampus and memory: insights from spatial processing. Nat Rev Neurosci 9:182–194
Bixby WR, Spalding TW, Hatfield BD (2001) Temporal dynamics and dimensional specificity of the affective response to exercise of varying intensity: differing pathways to a common outcome. J Sport Exerc Psychol 23:171–190
Boecker H, Sprenger T, Spilker ME, Henriksen G, Koppenhoefer M, Wagner KJ, Valet M, Berthele A, Tolle TR (2008) The runner's high: opioidergic mechanisms in the human brain. Cereb Cortex 18:2523–2531
Bradley MM, Lang PJ (2007) Emotion and motivation. In: Cacioppo JT, Tassinari LG, Bengtson GG (eds) Handbook of psychophysiology, 3rd edn. Cambridge University Press, New York, pp 581–607
Brümmer V, Schneider S, Abel T, Vogt T, Strüder HK (2011) Brain cortical activity is influenced by exercise mode and intensity. Med Sci Sports Exerc 43:1863–1872
Carlsson AM (1983) Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. Pain 16:87–101
Chaddock L, Erickson KI, Prakash RS, Kim JS, Voss MW, VanPatter M, Pontifex MB, Raine LB, Konkel A, Hillman CH, Cohen NJ, Kramer AF (2010) A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. Brain Res 1358:172–183
Chaddock L, Hillman CH, Buck SM, Cohen NJ (2011) Aerobic fitness and executive control of relational memory in preadolescent children. Med Sci Sports Exerc 43:344–349
Coan JA, Allen JJB (2007) Handbook of emotion elicitation and assessment. Oxford University Press, New York
Colcombe SJ, Erickson KI, Scalf PE, Kim JS, Prakash R, McAuley E, Elavsky S, Marquez DX, Hu L, Kramer AF (2006) Aerobic exercise training increases brain volume in aging humans. J Gerontol A Biol Sci Med Sci 61A:1166–1170
Colcombe SJ, Kramer AF (2003) Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychol Sci 14:125–130
Colcombe SJ, Kramer AF, Erickson KI, Scalf P, McAuley E, Cohen NJ, Webb A, Jerome GJ, Marquez DX, Elavsky S (2004) Cardiovascular fitness, cortical plasticity, and aging. Proc Natl Acad Sci USA 101:3316–3321
Coles K, Tomporowski PD (2008) Effects of acute exercise on executive processing, short-term and long-term memory. J Sports Sci 26:333–344
Cotman CW, Berchtold NC, Christie L-A (2007) Exercise builds brain health: key roles of growth factor cascades and inflammation. Trends Neurosci 30:464–472
Daley AJ (2002) Exercise therapy and mental health in clinical populations: is exercise therapy a worthwhile intervention? Adv Psychiatr Treat 8:262–270

Davidson RJ (1998) Affective style and affective disorders: perspectives from affective neuroscience. Cognition Emotion 12:307–330

Davranche K, Audiffren M (2009) A chronometric and electromyographic approach to the effect of exercise on reaction time. In: McMorris T, Tomporowski PD, Audiffren M (eds) Exercise and cognitive function. Wiley, Chichester, pp 153–159

Davranche K, Audiffren M, Denjean A (2006) A distributional analysis of the effect of physical exercise on a choice reaction time task. J Sports Sci 24:323–329

Del Giorno JM, Hall EE, O'Leary KC, Bixby WR, Miller PC (2010) Cognitive function during acute exercise: a test of the transient hypofrontality theory. J Sport Exerc Psychol 32:312–323

Dietrich A, Audiffren M (2011) The reticular-activating hypofrontality (RAH) model of acute exercise. Neurosci Biobehav Rev 35:1305–1325

Dietrich A, Sparling PB (2004) Endurance exercise selectively impairs prefrontal-dependent cognition. Brain Cogn 55:516–524

Dishman RK, Thom NJ, Puetz TW, O'Connor PJ, Clementz BA (2010) Effects of cycling exercise on vigor, fatigue, and electroencephalographic activity among young adults who report persistent fatigue. Psychophysiology 47:1066–1074

Eich TS, Metcalfe J (2009) Effects of the stress of marathon running on implicit and explicit memory. Psychon Bull Rev 16:475–479

Ekkekakis P (2008) Affect circumplex redux: the discussion on its utility as a measurement framework in exercise psychology continues. Int Rev Sport Exerc Psychol 1:139–159

Ekkekakis P, Hall EE, Petruzzello SJ (1999) Measuring state anxiety in the context of acute exercise using the State Anxiety Inventory: an attempt to resolve the brouhaha. J Sport Exerc Psychol 21:205–222

Ekkekakis P, Hall EE, Petruzzello SJ (2005a) Evaluation of the circumplex structure of the activation deactivation adjective check list before and after a short walk. Psychol Sport Exerc 6:83–101

Ekkekakis P, Hall EE, Petruzzello SJ (2005b) Variation and homogeneity in affective responses to physical activity of varying intensities: an alternative perspective on dose-response based on evolutionary considerations. J Sports Sci 23:477–500

Ekkekakis P, Petruzzello SJ (1999) Acute aerobic exercise and affect: current status, problems and prospects regarding dose–response. Sports Med 28:337–374

Ekman P, Friesen WV (1976) Pictures of facial affect. Consulting Psychologists Press, Palo Alto, C. A

Ekman P, Friesen WV (1978) Facial action coding system: a technique for the measurement of facial movement. Consulting Psychologists Press, Palo Alto

Elbe A-M, Szymanski B, Beckmann J (2005) The development of volition in young elite athletes. Psychol Sport Exerc 6:559–569

Elliott R, Zahn R, Deakin JFW, Anderson IM (2011) Affective cognition and its disruption in mood disorders. Neuropsychopharmacology 36:153–182

Erickson KI, Prakash RS, Voss MW, Chaddock L, Hu L, Morris KS, White SM, Wójcicki TR, McAuley E, Kramer AF (2009) Aerobic fitness is associated with hippocampal volume in elderly humans. Hippocampus 19:1030–1039

Eriksen BA, Eriksen CW (1974) Effects of noise letters on the identification of a target letter in a nonsearch task. Percept Psychophys 16:143–149

Etnier JL (2009) Chronic exercise and cognition in older adults. In: McMorris T, Tomporowski PD, Audiffren M (eds) Exercise and cognitive function. Wiley, Chichester, pp 227–247

Etnier JL, Chang YK (2009) The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. J Sport Exerc Psychol 31:469–483

Etnier JL, Nowell PM, Landers DM, Sibley BA (2006) A meta-regression to examine the relationship between aerobic fitness and cognitive performance. Brain Res Rev 52:119–130

Fillingim RB, Roth DL, Cook EW 3rd (1992) The effects of aerobic exercise on cardiovascular, facial EMG, and self-report responses to emotional imagery. Psychosom Med 54:109–120

Foerde K (2010) Implicit learning and memory: psychological and neural aspects. In: Koob GF, Le Moal M, Thompson RF (Eds) Encyclopedia of behavioral neuroscience. Elsevier Academic, pp 84–93
Frith CD, Gallagher H, Maguire E (2004) Mechanisms of control. In: Richard SJF, Karl JF, Christopher DF, Raymond JD, Cathy JP, Semir Z, John TA, William DP (eds) Human brain function, 2nd edn. Academic, Burlington, pp 329–362
Fumoto M, Oshima T, Kamiya K, Kikuchi H, Seki Y, Nakatani Y, Yu X, Sekiyama T, Sato-Suzuki I, Arita H (2010) Ventral prefrontal cortex and serotonergic system activation during pedaling exercise induces negative mood improvement and increased alpha band in EEG. Behav Brain Res 213:1–9
Gauvin L, Rejeski WJ (1993) The exercise-Induced feeling inventory: development and initial validation. J Sport Exerc Psychol 15:403–423
Gazzaley A, D'Esposito M (2007) Unifying prefrontal cortex function: executive control, neural networks and top-down modulation. In: Miller B, Cummings J (eds) The human frontal lobes: functions and disorders, 2nd edn. Guilford, New York, pp 187–206
Goldin PR, Hutcherson CAC, Ochsner KN, Glover GH, Gabrieli JDE, Gross JJ (2005) The neural bases of amusement and sadness: a comparison of block contrast and subject-specific emotion intensity regression approaches. Neuroimage 27:26–36
Graf P, Schacter DL (1985) Implicit and explicit memory for new associations in normal and amnesic subjects. J Exp Psychol Learn Mem Cogn 11:501–518
Grant DA, Berg EA (1948) A behavioural analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. J Exp Psychol Gen 38:404–411
Gray EK, Watson D (2007) Assessing positive and negative affect via self-report. In: Coan JA, Allen JJB (eds) Handbook of emotion elicitation and assessment. Oxford University Press, New York, pp 171–183
Gray MA, Minati L, Harrison NA, Gianaros PJ, Napadow V, Critchley HD (2009) Physiological recordings: basic concepts and implementation during functional magnetic resonance imaging. Neuroimage 47:1105–1115
Gronwall DM (1977) Paced auditory serial-addition task: a measure of recovery from concussion. Percept Mot Skills 44:367–373
Hall EE, Ekkekakis P, Petruzzello SJ (2010) Predicting affective responses to exercise using resting EEG frontal asymmetry: does intensity matter? Biol Psychol 83:201–206
Hamer M, Taylor A, Steptoe A (2006) The effect of acute aerobic exercise on stress related blood pressure responses: a systematic review and meta-analysis. Biol Psychol 71:183–190
Hardy CJ, Rejeski WJ (1989) Not what, but how one feels: the measurement of affect during exercise. J Sport Exerc Psychol 11:304–317
Hardy J, Hall CR, Alexander MR (2001) Exploring self-talk and affective states in sport. J Sports Sci 19:469–475
Hillman CH, Erickson KI, Kramer AF (2008) Be smart, exercise your heart: exercise effects on brain and cognition. Nat Rev Neurosci 9:58–65
Jackson EM, Dishman RK (2006) Cardiorespiratory fitness and laboratory stress: a meta-regression analysis. Psychophysiology 43:57–72
Jurado MB, Rosselli M (2007) The elusive nature of executive functions: a review of our current understanding. Neuropsychol Rev 17:213–233
Kamijo K, Nishihira Y, Hatta A, Kaneda T, Wasaka T, Kida T, Kuroiwa K (2004) Differential influences of exercise intensity on information processing in the central nervous system. Eur J Appl Physiol 92:305–311
Kaufman AS, Kaufman NL (1990) Kaufman brief intelligence test: manual. American Guidance Service, Circle Pines, MN
Kramer AF, Hahn S, Cohen NJ, Banich MT, McAuley E, Harrison CR, Chason J, Vakil E, Bardell L, Boileau RA, Colcombe A (1999) Ageing, fitness and neurocognitive function. Nature 400:418–419
Kreibig SD (2010) Autonomic nervous system activity in emotion: a review. Biol Psychol 84:394–421

Laborde S, Brüll A, Weber J, Anders LS (2011) Trait emotional intelligence in sports: a protective role against stress through heart rate variability? Personal Indiv Diff 51:23–27

Lambourne K, Tomporowski P (2010) The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. Brain Res 1341:12–24

Lang PJ, Bradley MM, Cuthbert BN (2008) International affective picture system (IAPS): affective ratings of pictures and instruction manual. Technical Report A-8. The Centre for Research in Psychophysiology, University of Florida, Gainesville, FL

Leunes A, Burger J (2000) Profile of mood states research in sport and exercise psychology: past, present, and future. J Appl Sport Psychol 12:5–15

Lezak MD, Howieson DB, Loring DW (2004) Neuropsychological assessment, 4th edn. Oxford University Press, New York

Malik M (1996) Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Eur Heart J 17:354–381

Martens R, Burton D, Vealey RS, Bump LA, Smith DE (1990) Development and validation of the Competitive State Anxiety Inventory-2 (CSAI-2). In: Martens R, Vealey RS, Burton D (eds) Competitive anxiety in sport. Human Kinetics, Champaign, IL, pp 193–208

Martinent G, Ferrand C, Guillet E, Gautheur S (2010) Validation of the French version of the Competitive State Anxiety Inventory-2 Revised (CSAI-2R) including frequency and direction scales. Psychol Sport Exerc 11:51–57

McMorris T (2008) Exercise and cognition: towards an inter-disciplinary model. Open Sports Med J 2:60–68

McMorris T, Sproule J, Turner A, Hale BJ (2011) Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: a meta-analytical comparison of effects. Physiol Behav 102:421–428

McNair D, Lorr M, Droppelman L (1971) Profile of mood states. Educational and Industrial Testing Service, San Diego, CA

Miller EK, Cohen JD (2001) An integrative theory of prefrontal cortex function. Annu Rev Neurosci 24:167–202

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD (2000) The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: a latent variable analysis. Cogn Psychol 41:49–100

Mneimne M, McDermut W, Powers AS (2008) Affective ratings and startle modulation in people with nonclinical depression. Emotion 8:552–559

Monsell S (2003) Task switching. Trends Cogn Sci 7:134–140

Moraes H, Deslandes A, Silveira H, Ribeiro P, Cagy M, Piedade R, Pompeu F, Laks J (2011) The effect of acute effort on EEG in healthy young and elderly subjects. Eur J Appl Physiol 111:67–75

Morgan WP (1997) Methodological considerations. In: Morgan WP (ed) Physical activity and mental health. Taylor & Francis, Washington, DC, pp 3–32

Murray NP, Raedeke TD (2008) Heart rate variability as an indicator of pre-competitive arousal. Int J Sport Psychol 39:346–355

Nadel L, Hardt O (2011) Update on memory systems and processes. Neuropsychopharmacology 36:251–273

Navon D (1977) Forest before trees: the precedence of global features in visual perception. Cogn Psychol 9:353–383

Oda S, Matsumoto T, Nakagawa K, Moriya K (1999) Relaxation effects in humans of underwater exercise of moderate intensity. Eur J Appl Physiol Occup Physiol 80:253–259

Panksepp J (1988) Brain emotional circuits and psychopathologies. In: Clynes M, Panksepp J (eds) Emotions and psychopathology. Plenum, New York, pp 37–76

Parkinson B, Totterdell P, Briner RB, Reynolds S (1996) Changing moods: the psychology of mood and mood regulation. Longman, London

Pereira AC, Huddleston DE, Brickman AM, Sosunov AA, Hen R, McKhann GM, Sloan R, Gage FH, Brown TR, Small SA (2007) An in vivo correlate of exercise-induced neurogenesis in the adult dentate gyrus. Proc Natl Acad Sci USA 104:5638–5643

Pesce C, Tessitore A, Casella R, Pirritano M, Capranica L (2007) Focusing of visual attention at rest and during physical exercise in soccer players. J Sports Sci 25:1259–1270

Petruzzello SJ, Hall EE, Ekkekakis P (2001) Regional brain activation as a biological marker of affective responsivity to acute exercise: influence of fitness. Psychophysiology 38:99–106

Pontifex MB, Hillman CH, Fernhall B, Thompson KM, Valentini TA (2009) The effect of acute aerobic and resistance exercise on working memory. Med Sci Sports Exerc 41:927–934

Reed J, Buck S (2009) The effect of regular aerobic exercise on positive-activated affect: a meta-analysis. Psychol Sport Exerc 10:581–594

Reed J, Ones DS (2006) The effect of acute aerobic exercise on positive activated affect: a meta-analysis. Psychol Sport Exerc 7:477–514

Rhodes RE, Smith NE (2006) Personality correlates of physical activity: a review and meta-analysis. Br J Sports Med 40:958–965

Robbins TW (2007) Shifting and stopping: fronto-striatal substrates, neurochemical modulation and clinical implications. Phil Transact R Soc Lond B Biol Sci 362:917–932

Rodrigues AVS, Martinez EC, Duarte AFA, Ribeiro LCS (2007) Aerobic fitness and its influence in the mental stress response in army personnel. Revista Brasileira de Medicina do Esporte 13:113–117

Russell JA, Weiss A, Mendelsohn GA (1989) Affect grid: a single-item scale of pleasure and arousal. J Pers Soc Psychol 57:493–502

Scherer KR, Peper M (2001) Psychological theories of emotion and neuropsychological research. In: Boller F, Grafman J, Gainotti G (eds) Handbook of neuropsychology, vol 5, Emotional behavior and its disorders. Elsevier, Amsterdam, pp 17–48

Schneider M, Graham D, Grant A, King P, Cooper D (2009a) Regional brain activation and affective response to physical activity among healthy adolescents. Biol Psychol 82:246–252

Schneider S, Brümmer V, Abel T, Askew CD, Strüder HK (2009b) Changes in brain cortical activity measured by EEG are related to individual exercise preferences. Physiol Behav 98: 447–452

Shohamy D, Myers CE, Kalanithi J, Gluck MA (2008) Basal ganglia and dopamine contributions to probabilistic category learning. Neurosci Biobehav Rev 32:219–236

Sibley BA, Beilock SL (2007) Exercise and working memory: an individual differences investigation. J Sport Exerc Psychol 29:783–791

Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P (2008) Exercise, fitness, and neurocognitive function in older adults: the "selective improvement" and "cardiovascular fitness" hypotheses. Ann Behav Med 36:280–291

Smith A (1982) Symbol digit modalities test: manual (revised). Western Psychological Services, Los Angeles

Smith JC, Cook DB (2005) Methodology in psychophysiological studies: applications in physical activity. Int J Sport Exerc Psychol 3:534–553

Smith JC, Crabbe JB (2000) Emotion and exercise. Int J Sport Psychol 31:156–174

Smith JC, O'Connor PJ (2003) Physical activity does not disturb the measurement of startle and corrugator responses during affective picture viewing. Biol Psychol 63:293–310

Smith PJ, Blumenthal JA, Hoffman BM, Cooper H, Strauman TA, Welsh-Bohmer K, Browndyke JN, Sherwood A (2010) Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. Psychosom Med 72:239–252

Spielberger CD, Gorsuch RL, Lushene RE (1970) Manual for the state-trait anxiety inventory. Consulting Psychologists Press, Palo Alto, CA

Spirduso WW, Poon LW, Chodzko-Zajko W (2008) Using resources and reserves in an exercise-cognition model. In: Spirduso WW, Poon LW, Chodzko-Zajko W (eds) Exercise and its mediating effects on cognition. Human Kinetics, Champaign, IL, US, pp 3–11

Squire LR (2004) Memory systems of the brain: a brief history and current perspective. Neurobiol Learn Mem 82:171–177

Stephens CL, Christie IC, Friedman BH (2010) Autonomic specificity of basic emotions: evidence from pattern classification and cluster analysis. Biol Psychol 84:463–473

Steptoe A, Cox S (1988) Acute effects of aerobic exercise on mood. Health Psychol 7:329–340

Steptoe A, Kearsley N, Walters N (1993) Acute mood responses to maximal and submaximal exercise in active and inactive men. Psychol Health 8:89–99
Steptoe A, Moses J, Mathews A, Edwards S (1990) Aerobic fitness, physical activity, and psychophysiological reactions to mental tasks. Psychophysiology 27:264–274
Stern RA, Arruda JE, Hooper CR, Wolfner GD, Morey CE (1997) Visual analogue mood scales to measure internal mood state in neurologically impaired patients: description and initial validity evidence. Aphasiology 11:59–71
Stern Y (2009) Cognitive reserve. Neuropsychologia 47:2015–2028
Strauss E, Sherman EMS, Spreen O (2006) A compendium of neuropsychological tests: administration, norms, and commentary, 3rd edn. Oxford University Press, New York
Stroth S, Hille K, Spitzer M, Reinhardt R (2009) Aerobic endurance exercise benefits memory and affect in young adults. Neuropsychol Rehabil 19:223–243
Stroth S, Reinhardt RK, Thöne J, Hille K, Schneider M, Härtel S, Weidemann W, Bös K, Spitzer M (2010) Impact of aerobic exercise training on cognitive functions and affect associated to the COMT polymorphism in young adults. Neurobiol Learn Mem 94:364–372
Stuss DT (2007) New approaches to prefrontal lobe testing. In: Miller BL, Cummings JL (eds) The human frontal lobes: functions and disorders, 2nd edn. Guilford, New York
Swick D, Ashley V, Turken U (2011) Are the neural correlates of stopping and not going identical? Quantitative meta-analysis of two response inhibition tasks. Neuroimage 56:1655–1665
Szabo A, Bak M (1999) Exercise-induced affect during training and competition in collegiate soccer players. European Yearbook of Sport Psychology 3:91–104
Taylor SF, Phan KL, Decker LR, Liberzon I (2003) Subjective rating of emotionally salient stimuli modulates neural activity. Neuroimage 18:650–659
Thayer JF, Lane RD (2009) Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. Neurosci Biobehav Rev 33:81–88
Thayer RE (1989) The biopsychology of mood and arousal. Oxford University Press, New York
Themanson JR, Hillman CH (2006) Cardiorespiratory fitness and acute aerobic exercise effects on neuroelectric and behavioral measures of action monitoring. Neuroscience 141:757–767
Themanson JR, Hillman CH, Curtin JJ (2006) Age and physical activity influences on action monitoring during task switching. Neurobiol Aging 27:1335–1345
Themanson JR, Pontifex MB, Hillman CH (2008) Fitness and action monitoring: evidence for improved cognitive flexibility in young adults. Neuroscience 157:319–328
Tian Q, Smith JC (2011) Attentional bias to emotional stimuli is altered during moderate- but not high-intensity exercise. Emotion 11:1415–1424
Tomporowski PD (2009) Methodological issues: research approaches, research design, and task selection. In: McMorris T, Tomporowski PD, Audiffren M (eds) Exercise and cognitive function. Wiley, Chichester, pp 91–113
Tomporowski PD, Davis CL, Miller PH, Naglieri JA (2008) Exercise and children's intelligence, cognition, and academic achievement. Educ Psychol Rev 20:111–131
Tomporowski PD, Ganio MS (2006) Short-term effects of aerobic exercise on executive processing, memory, and emotional reactivity. Int J Sport Exerc Psychol 4:57–72
van Zomeren AH, Brouwer WH (1994) Clinical neuropsychology of attention. Oxford University Press, New York
Vlachopoulos S, Biddle SJH, Fox K (1996) A social cognitive investigation into the mechanisms of affect generation in children's physical activity. J Sport Exerc Psychol 18:174–193
Vogt T, Schneider S, Brümmer V, Strüder HK (2010) Frontal EEG asymmetry: the effects of sustained walking in the elderly. Neurosci Lett 485:134–137
Voss MW, Prakash RS, Erickson KI, Basak C, Chaddock L, Kim JS, Alves H, Heo S, Szabo AN, White SM, Wojcicki TR, Mailey EL, Gothe N, Olson EA, McAuley E, Kramer AF (2010) Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. Front Aging Neurosci 2:32
Watson D, Clark LA, Tellegen A (1988) Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol 54:1063–1070

Wechsler D (2008) Wechsler adult intelligence scale-fourth edition (WAIS-IV). Pearson, San Antonio, TX

Wechsler D (2009) Wechsler memory scales, 4th edn. Pearson, San Antonio, TX

Williams DM, Dunsiger S, Ciccolo JT, Lewis BA, Albrecht AE, Marcus BH (2008) Acute affective response to a moderate-intensity exercise stimulus predicts physical activity participation 6 and 12 months later. Psychol Sport Exerc 9:231–245

Williamson JD, Espeland M, Kritchevsky SB, Newman AB, King AC, Pahor M, Guralnik JM, Pruitt LA, Miller ME (2009) Changes in cognitive function in a randomized trial of physical activity: Results of the Lifestyle Interventions and Independence for Elders Pilot Study. J Gerontol A Biol Sci Med Sci 64A:688–694

Winter B, Breitenstein C, Mooren FC, Voelker K, Fobker M, Lechtermann A, Krueger K, Fromme A, Korsukewitz C, Flöel A, Knecht S (2007) High impact running improves learning. Neurobiol Learn Mem 87:597–609

Wipfli BM, Rethorst CD, Landers DM (2008) The anxiolytic effects of exercise: a meta-analysis of randomized trials and dose-response analysis. J Sport Exerc Psychol 30:392–410

Woo M, Kim S, Kim J, Petruzzello SJ, Hatfield BD (2009) Examining the exercise-affect dose-response relationship: does duration influence frontal EEG asymmetry? Int J Psychophysiol 72:166–172

Yeung RR (1996) The acute effects of exercise on mood state. J Psychosom Res 40:123–141

Zald DH, Andreotti C (2010) Neuropsychological assessment of the orbital and ventromedial prefrontal cortex. Neuropsychologia 48:3377–3391