10 Complex Motor Activities to Enhance Cognition

David Moreau and Phillip D. Tomporowski

1 Introduction

Decades of research have shown that training on a task typically leads to enhanced performance, provided certain task parameters remain consistent across training (for an example in the motor domain, see Schmidt and Wrisberg 2008). This line of work has paved the way for entire programs of research focusing on task-specific improvements and their neural correlates (e.g., Ericsson, Krampe, and Tesch-Römer 1993). When considering cognitive enhancement, however, a more exciting prospect is for training to elicit improvements on a *different* task (i.e., transfer). Finding effective means of transfer could have tremendous implications both in refining theoretical models of cognition and in terms of applications to clinical fields (e.g., Hertzog et al. 2008).

With this in mind, it is not surprising that brain training programs have flourished in the past few years. Often compared with physical exercise regimens, the idea of enhancing brain function through cognitive training is appealing, and has the potential to impact a wide range of real-life activities. Yet, as attractive as the premise is, findings have remained mixed so far (Au et al. 2014; Harrison et al. 2013; Hovik et al. 2013; Jaeggi et al. 2008; Jaeggi et al. 2011; Lampit, Hallock, and Valenzuela 2014; Redick et al. 2013; Rudebeck et al. 2012; Shipstead, Redick, and Engle 2012; Thompson et al. 2013), and have yet to demonstrate meaningful transfer. In line with mixed evidence, one consideration that has gained traction in recent discussions is the idea of opportunity costs (e.g., Moreau and Conway 2014): Is time spent playing training games wisely invested?

Here, we provide a tentative answer to this legitimate question, with a discussion of cognitive training regimens based on physical activity. Specifically designed to be challenging at the cognitive and physical levels, such regimens have the potential to elicit core improvements. Before presenting the rationale for this approach, we briefly discuss the mechanisms underlying the effect of physical exercise on cognition, as well as the fundamental aspects of effective learning. We conclude with a broader discussion of the impact of this line of research to cognitive training paradigms.

2 Physical Exercise, Neurogenesis, and Cognition

Physical exercise has been related to changes in neurobiological components, brain structure, brain function, and behavior. These have been documented for decades, both via animal and human experiments. Here, we provide a description of each of these, going from lower to higher levels (i.e., from neurobiology to behavior).

2.1 Neurobiological Mechanisms

Physical exercise is associated with myriad of benefits, some of which can be measured at the neurobiological level. For instance, exercise facilitates cerebral vascularization (Black et al. 1990) and brain insult resistance (Stummer et al. 1994) and increases concentrations of specific proteins and neurotransmitters (Mora, Segovia, and del Arco 2007). Exercise also affects neurogenesis and angiogenesis (Black et al. 1990; Praag et al. 2002; Praag, Kempermann, and Gage 1999) and contributes to neuronal survival and enhanced synaptic metabolism (Vaynman et al. 2006). Together, these processes suggest that exercise directly contributes to the maintenance of healthier, more efficient neural systems.

More specifically, brain-derived neurotrophic factor (BDNF) is thought to mediate many of the benefits of exercise on cognition. Evidence for the role of BDNF in this process originated in animal models (Neeper et al. 1995). BDNF concentration is typically increased after exercise (Ferris, Williams, and Shen 2007; Griffin et al. 2011; Schmolesky, Webb, and Hansen 2013), from within minutes to days, and can last up to several weeks (Berchtold et al. 2001). This effect appears to be most notable in the hippocampus, the caudal neocortex, and the dentate gyrus (Neeper et al. 1996). Importantly, Neeper and colleagues note that these regions are not primarily involved in motor control, and thus that increases in BDNF concentrations directly influence areas involved in cognitive function (Neeper et al. 1996).

It has been suggested that the increase in BDNF concentrations post-exercise is itself triggered by the release of insulin-like growth factor-1 (IGF-1; Cotman and Berchtold 2002), a growth factor involved in neuronal development (Arsenijevic and Weiss 1998). Because IGF-1 plays a role in cell proliferation and survival (Huat et al. 2014), it is also thought to be a very important contributor to memory consolidation and enhancement (Chen et al. 2011). Similarly, fibronectin type III domain-containing protein 5 (FNDC5) is suspected to mediate some of the effects of BDNF on brain function, particularly on hippocampal cell proliferation, via an effect on the activation of the BDNF gene (Boström et al. 2012). A detailed account of the neurobiological mechanisms underlying exercise is beyond the scope of this chapter, yet overall these findings suggest that physical exercise triggers a cascade of complex molecular processes via direct and indirect pathways, with significant impact on brain function and thus on cognition.

Beside direct positive effects, physical exercise also leads to benefits through downregulation of harmful factors. For example, exercise counteracts some of the deleterious effects of stress. When unaddressed, prolonged stress leads to the release of corticosteroids, hormones that negatively affect BDNF levels in the brain and can lead to neuronal degradation and dendritic atrophy (Gould et al. 1990). Exercise acts as a protective mechanism, an effect particularly pronounced in the hippocampus (Russo-Neustadt et al. 2001). The benefit of physical exercise on the concentration of several neurotransmitters has also been documented; in particular, monoamine (e.g., dopamine, epinephrine, norepinephrine) and tryptamine neurotransmitters (e.g., serotonin, melatonin) play a critical role in a wide range of neural processes. These neurobiological effects are thought to be associated with many of the observed effects on cognition (Praag et al. 1999; Winter et al. 2007), although pinpointing the exact mechanisms and interactions between neurotransmitters remains particularly difficult. Regardless, this body of work clearly underlines the importance of neurobiological factors in mediating the relationship between physical exercise and cognition.

2.2 Functional and Structural Changes

Additional exercise-induced changes at the structural and functional levels further demonstrate the potency of the neurobiological mechanisms aforementioned. Several randomized-controlled experiments have shown that physical exercise engenders wide benefits on brain function, often demonstrated with EEG or fMRI techniques (Chaddock-Heyman et al. 2013; Davis et al. 2011; Hillman et al. 2014; Kamijo et al. 2011). For example, Chaddock-Heyman and colleagues (2013) reported that children who engaged in sixty minutes of physical activity every week day for a school year showed decreases in BOLD signal in areas of the right anterior prefrontal cortex when performing a cognitive control task. Importantly, these changes in fMRI activation were also associated with behavioral improvements on this particular task. Davis and colleagues, on the other hand, found that thirteen weeks of exercise, half an hour a day, led to improved executive functions but increased bilateral prefrontal activity (Davis et al. 2011). Apparently disparate, these results suggest that complex factors are associated with cortical activity and enhanced performance on behavioral tasks, mirroring corroborating findings in more general literatures (e.g., Xu, Calhoun, and Potenza 2015).

Other, coarser brain changes have also been documented. For example, diffusion tensor imaging (DTI) studies in children suggest that physical exercise interventions leads to greater white-matter integrity, especially in the uncinate fasciculus (Schaeffer et al. 2014) and the superior longitudinal fasciculus (Krafft et al. 2014). These two tracts are fundamental networks involved in connecting the limbic system and the prefrontal cortex, and the temporal and parietal lobes, respectively. Observational evidence corroborates these findings, with noticeable white-matter integrity differences among children of various fitness levels (Chaddock-Heyman et al. 2014).

Further dramatic neural changes can typically be observed in older populations. For example, exercise regimens can potentially alleviate age-related brain atrophy and loss of brain tissue density (Colcombe et al. 2003), and it has been suggested that such direct relationship might explain the correlation between indices of reported aerobic fitness and cognitive function, especially executive processes (Weinstein et al. 2012). This potential for exercise to counteract the effects of aging on the brain is particularly significant when considering that brain atrophy is associated with both normal cognitive decline (Kooistra et al. 2014) and dementia (Bilello et al. 2015). Higher fitness is also correlated with larger hippocampus (Weinstein et al. 2012) and cortical areas (Erickson et al. 2009; Makizako et al. 2015), findings that are consistent with experimental evidence based on training designs (Colcombe et al. 2006; Erickson et al. 2011; Ruscheweyh et al. 2011). Finally, physical fitness also correlates with long-term potentiation (LTP), assessed through changes in the N1b component of visual-evoked potentials (Smallwood et al. 2015), suggesting that physical exercise may have a direct impact on human LTP.

2.3 Cognitive and Behavioral Improvements

Directly in line with the functional and structural changes previously described, individuals showing better self-reported fitness also tend to outperform less fit individuals on measures of executive functions and of spatial reasoning (Colcombe and Kramer 2003; Hillman, Erickson, and Kramer 2008). Some studies have suggested that the relationship between physical exercise and cognitive performance may be restricted to executive function tasks, at least in older adults (e.g., Kramer, Hahn, and Gopher 1999), yet broader literature would suggest that this link goes well beyond executive functions, with a wide range of cognitive abilities being associated with physical exercise habits and fitness indices. These include perceptual and spatial abilities, both fundamental to many of our day-to-day activities (see, for a review, Moreau and Conway 2013).

Adding to this line of research, complementary studies have sought to identify causal relationships between exercising and cognitive outcomes. For example, exercise interventions have been shown to improve attention in children with developmental coordination disorders (Tsai, Wang, and Tseng 2012) and in individuals with attention-deficit/hyperactivity disorder (ADHD, Archer and Kostrzewa 2012). Perhaps even more remarkable, a training intervention by Davis and colleagues found dose-response benefits of exercise on executive functions and mathematics achievement (2007). This finding is corroborated by other studies, which have found an association between physical fitness and both mathematics and reading achievement (Castelli et al. 2007), as well as between physical activity and overall academic grades (Coe et al. 2006). These studies reflect a general trend showing consistent associations between physical exercise, physical activity, fitness indices, and academic achievement (Donnelly et al. 2016; Keeley and Fox 2009).

Physical exercise is also associated with lower risks for mental and neurological conditions. A review by Penedo and Dahn (2005) found that many conditions, among them autism, ADHD, schizophrenia, dementia, and Alzheimer's disease, appear to benefit from exercise interventions, and poor physical fitness tends to exacerbates their associated symptoms. Consistent with the findings reported in this review, studies of older populations have found that exercise is linked to emotional stability (Blumenthal et al. 1991), better associative learning (Fabre et al. 2002), and improved cognition (Cancela Carral and Ayán Pérez 2007). We should point out, however, that the direct influence of exercise interventions in older people without cognitive impairment was recently questioned in a meta-analysis by the Cochrane Collaboration, which found "no evidence in the available data from RCTs that aerobic physical activities, including those which successfully improve cardiorespiratory fitness, have any cognitive benefit in cognitively healthy older adults" (Young et al. 2015, abstract). Because physical exercise interventions encompass a wide, often disparate range of training regimens, this finding highlights the need to further specify which interventions are the most effective to elicit robust and meaningful cognitive changes.

3 Learning and Synaptogenesis

One aspect that is often left out when seeking cognitive enhancement via physical exercise is the role of learning. As we have alluded to in the previous section, the human brain can produce up to tens of thousands of new cells every day, a process facilitated by physical exercise. Many of these, however, die out within a few weeks (Gould et al. 1999). This process may seem wasteful, yet it ensures that new cells are available when needed. Undoubtedly, physical exercise is a critical factor in the genesis of neural cells, but these are different from functional neurons. Many of these new cells may never mature into functional neurons, unless the right conditions are in place for their development. In particular, cell survival requires neurons to make contact with one another, a process called synaptogenesis, which is largely enhanced when physical exercise is accompanied by learning (Gould et al. 1999; Leuner et al. 2004). Thus, targeting cognitive enhancement based solely on physical exercise appears to be insufficient. An optimal solution may reside in combination with effortful learning, as we discuss hereafter.

3.1 Core Mechanisms and Function

In the adult human brain, many of the new neurons are generated in the hippocampus, a brain structure associated with various components of learning. Such localized process suggests that certain aspects of hippocampal-dependent learning can greatly benefit from a pool of continuously renewed neurons. Interestingly, the beneficial aspect of hippocampal neurogenesis was questioned a few decades ago by Pasko Rakic, who hypothesized that adult neurogenesis was not found in the primate brain for the purpose of network stability (Rakic 1985). Known as the stability-plasticity dilemma, his postulate was based on the assumption that systems that emphasize plasticity will learn easily, but storage will be compromised. At the other end of what can be thought of as a continuum, systems that favor stability can maintain information for a long time, but at the detriment of novel learning. Therefore, it follows that different systems may favor different positions on the stability-plasticity continuum, and Rakic's argument against adult neurogenesis was based on the idea that new neurons would be too disruptive to network stability in humans. Although plausible, this hypothesis has since been discarded, and neurogenesis is now thought of as part of the solution to the stability-plasticity dilemma, rather than as a fundamental problem irreconcilable with the notion of neurogenesis (Kempermann, Wiskott, and Gage 2004).

Provided that, over time, evolution has favored a plentiful supply of neurons in the hippocampus to facilitate learning (Amrein and Lipp 2009), it seems plausible that the act of learning itself would favor neuron survival. Note that these two processes operate on substantially different timescales, and therefore that the direct effect of learning on neuron survival needed experimental validation. More than fifteen years ago, Gould and colleagues provided that missing link. They reported that new neurons in the hippocampus of adult rodents could be rescued from death by learning and that new hippocampal neurons were involved in memory formation (Gould et al. 1999). Subsequent experiments have consistently demonstrated that not all types of learning are created equal when it comes to neuron survival (Curlik and Shors 2011; Waddell, Anderson, and Shors 2011): specific components appear to be critical in this complex process.

3.2 Enhancing Cell Survival via Effortful Learning

Research with animal models indicates that learning that depends on the hippocampus, such as conditioning or spatial navigation tasks, tend to increase neuron survival (Anderson et al. 2011). This is consistent with the idea that most new neurons originate in the hippocampus (Praag et al. 2002), although additional findings indicate that neuron survival can sometimes be dissociated from hippocampal involvement (Shors 2014). Together, this line of work suggests that effort might be the common feature in all tasks that favor neuron survival—difficulty forces neural adaptations in order to cope with new demands. The underlying rationale is that the neural system needs to be stressed up to a point where it needs additional resources (e.g., new neurons) to perform adequately. Interestingly, this rationale is also consistent with behavioral studies in humans, which have found that training on complex tasks offering sustained difficulty induces greater cognitive improvements than less complex regimens (e.g., Moreau, Morrison, and Conway 2015).

Moreover, individuals who find tasks more difficult and therefore need more time to reach a given level of performance rescue more neurons from death than those who reach that same level of performance easily (Nokia et al. 2012). Importantly, this is predicated on the fact that the individual is continuously learning (Curlik and Shors 2011). This is interesting because it suggests that effortful learning might mitigate initial disparities, by reducing gaps and differences. Once new neurons have been rescued from death, they can remain in the hippocampus several months (Curlik and Shors 2013). These neurons are also functional, which means that they have made contact with other neurons and can produce action potentials (Praag et al. 2002). The idea that learning can favor neuron survival has influenced research in many areas, including in the recent field of cognitive training.

3.3 Cognitive Training

Stemming from studies in the field of neurogenesis, the rationale for cognitive training is rather straightforward. Generally, training cognition involves focused, often repetitive, practice of a single or a set of cognitive tasks. What differentiates this form of training from typical learning following deliberate practice (Ericsson et al. 1993) is that in the case of cognitive training the regimen is designed to elicit improvements in other, different tasks (i.e., transfer). That this form of training leads to improvements in the ability or abilities targeted (near-transfer) is commonly accepted, even by skeptics of this approach (e.g., Harrison et al. 2013), provided adequate training design. Such improvements have also been correlated with functional and structural changes in the brain, for example regarding connectivity in the frontoparietal network (Caeyenberghs et al. 2016). What remains a matter of discussion, however, is the potential for such regimens to elicit substantial improvements outside of the trained abilities, particularly in ecological situations. Early findings of transfer (Jaeggi et al. 2008, 2014; Rudebeck et al. 2012) have failed to replicate in several subsequent studies (Redick et al. 2013; Thompson et al. 2013), resulting in some degree of skepticism over the validity of the rationale (Melby-Lervåg and Hulme 2013; Moreau and Conway 2014). In this context, more recent studies have emphasized the need to understand the underlying mechanisms of such discrepancies (Jaeggi et al. 2014; Moreau, Kirk, and Waldie 2016; Moreau 2014), so as to offer better, more potent interventions (Moreau and Waldie 2016).

4 Movement, Learning, and Cognition across the Lifespan

One particular approach that has shown promise is based on movement. Arguably, the recent surge of studies in the field of cognitive training has largely left out decades of research linking physical exercise and cognitive enhancement. Based on the current understanding of the underlying mechanisms mediating this relationship, such segregation seems unwise. Beyond a mere juxtaposition of research paradigms, and in order to understand the added value of situations involving complex motor coordination, it is helpful to describe the role of movement across the lifespan. We illustrate the relevance of this line of research to cognitive training in the following discussion.

4.1 Movement and Early Learning

Three long-standing lines of research and inquiry have focused on cognitive development: psychologists have concentrated on children's mental development, physical educators have observed and assessed the development and maturation of fundamental movement skills, and teachers have created pedagogical approaches to maximize learning. For over a century, considerable theoretical advances have been made within each of these areas; however, until recently, relatively little cross-disciplinary discussions have emerged. Currently, several researchers have emphasized the importance of understanding how cognitive development may be explained in terms of the interplay among these three lines of inquiry (Pesce et al. 2016).

The mental world of the infant has long intrigued parents and scientists alike. William James, who influenced the emergence of modern psychology, considered infancy to be a situation in which the baby's impression of the world was "one great blooming, buzzing confusion" (James [1890] 1981, 462). Modern research has revealed that James's view of infancy may not be entirely accurate; rather, as expressed by the influential developmental psychologist Esther Thelen, "The foundations of complex human thought and behavior have their origins in action and are always embedded in a history of acting" (Thelen 2004, 49). Infant learning is grounded in action that provides information concerning the infant's movements in space. Sensory experiences that occur with movement provide the bases of learning via action and perception.

During reaching movements, the infant's neural networks develop that later provide the basis for self-generated arm movements that provide viable solutions to task demands. Self-initiated responses reflect the biomechanics of the body, speed, and force of the action, and of environmental conditions presented at a particular point in time (Spencer et al. 2006). The contraction and lengthening of skeletal muscle build and refine neural networks that serve as the building blocks of skilled movement. These emerging networks also receive input from multiple sensory systems that provide information concerning the location of objects in the infant's world. Early research by Thelen and her colleagues demonstrated that the integration of sensory information from skeletal muscles and other systems is critical for infants' normal cognitive development (Thelen 1995). Indeed, children who lack sufficient interactions with their environment may fail to acquire the predictive control of actions that is vital for meeting the challenges faced during the first few years of life. For example, children with pervasive developmental delay (e.g., the autism spectrum) often show deficits in many areas of daily-life functioning (clumsiness, poor language, inappropriate social behavior). For these children, mental development may be supported by engaging in physical activities that lead to the generation of novel physical actions, thus favoring successful problem solving.

4.2 Movement and Executive Functions

The observation that young children diagnosed with autism and other developmental disorders often show poor motor coordination, high movement variability, and difficulty in predicting the sensory consequences of actions led several researchers in the fields of psychology (Diamond 2000) and motor development (Ben-Soussan, Glicksohn, and Berkovich-Ohana 2015) to consider the neurological development of the central nervous system: in particular, the emerging relation between the cerebellum and prefrontal cortex. Diamond's influential paper summarized existing neurophysiological evidence for a close interrelationship between the developing prefrontal cortex and the cerebellum (Diamond 2000). The cerebellum, because of its role in the control of discrete, rapid movements, was long considered to be involved primarily in motor skills. Similarly, the prefrontal cortex was viewed to be involved primarily in complex cognitive processes. Developmental neurophysiological evidence, however, suggests that bidirectional communication between the dorsolateral cortex and cerebellum via connection in the basal ganglia is critical for both executive processing and motor control. While the specific role of the relationship between cerebellum and prefrontal cortex has been debated (Leiner, Leiner, and Dow 1986, 1989, 1993), contemporary research in motor development tends to substantiate bidirectional views (Ben-Soussan et al. 2015).

The emergence of executive functions during early childhood has received considerable study and debate (Diamond 2013). During early childhood, children evidence changes in the ability to keep information in working memory, inhibit behaviors when appropriate, and to alternate actions when environmental conditions change. These behaviors are taken to reflect the emergence of the basic components of executive functions: updating, inhibition, and switching (Miyake et al. 2000). As addressed above, brain imaging studies reveal that specific neural prefrontal networks in the prefrontal cortex are established and circuitry with other brain structures is developed during childhood. Given the nature of executive functions, the cognitive-motor linkages between the dorsolateral prefrontal cortex and the cerebellum are essential. Executive control requires timed motor coordination and movement control when a child is faced with the need to allocate attention to a new task, when task conditions change, and when rapid actions are needed (Diamond 2000). Executive functions are particularly important when children encounter novel conditions that promote learning. Through planned actions, children experience and store the memories of their actions, the consequences of the actions, and the context in which the actions occurred. For these reasons, play, games, and sports provide unique contexts to promote mental development and learning.

4.3 Movement and Cognition beyond Development

Beside its impact on cognitive development, movement also has important implications across the lifespan. In particular, recent research in the field of embodied cognition has underlined the fundamental aspect our bodies, actions, and movements play in shaping cognition, and how action and cognition are inherently intertwined (Barsalou 2008; Gallese and Sinigaglia 2011; Glenberg 2010).

This interrelation has been studied in various contexts. For example, it has been demonstrated that expertise in a particular motor skill is typically associated with enhanced performance on a range of motor processing tasks (Güldenpenning et al. 2011), but also with other abilities outside the motor domain. These include cognitive abilities such as working memory capacity and spatial ability (Lehmann and Jansen 2012; Moreau 2012a, 2013), but also language (Holt and Beilock 2006), a skill thought to be removed from so-called lower-order motor mechanisms until recently.

The notion that the motor system is involved in many cognitive processes is further supported by research on the mirror system. Mirror neurons fire both when one performs an action and when one observes the same action being performed (Rizzolatti and Craighero 2004). This bidirectional neural mechanism has been put forward to explain our capacity to learn by observation and imitation (Oztop, Kawato, and Arbib 2006), and has been proposed as a central component mediating the influence of motor simulation to shape representations in the motor system (Jeannerod 2001). Indeed, motor simulation allows control over malleable motor representations, in the absence of overt movement (Jeannerod and Decety 1995), and motor actions allows alterations in the mental representations of movement (de Lange, Roelofs, and Toni 2008), therefore emphasizing the interdependent relationship between imagery and movement.

In addition, the mirror system has been established as a fundamental pillar of our ability to understand others' actions (Gallese 1998), and thus of our ability to navigate in social contexts (Schulkin 2000). Although it should be mentioned that the influence of the mirror system might have been exaggerated in some instances (Hickok 2009), the basic mechanisms underlying the relationship between action and cognition remain largely informative, especially for understanding the consequences of movement on human cognitive abilities. Together, this body of work supports the idea that motor actions ground mental representation in action (Beilock and Goldin-Meadow 2010), and therefore that movement itself is central to cognition. That is not to say that all cognition is embodied, as it cannot be excluded that some forms of thinking have evolved to be disembodied (Dove 2010), but it suggests that the role of movement in shaping and maintaining cognitive abilities cannot be dismissed and, more importantly, should be capitalized on.

5 Movement-Based Interventions to Enhance Cognition

Several researchers have proposed that optimal enhancement could be achieved through a form of exercise that incorporates difficult and challenging tasks. Possibilities are numerous, but results have been particularly promising when complex motor learning is combined with exercise (Curlik et al. 2013; Moreau, Morrison, and Conway 2015; Tomporowski, Lambourne, and Okumura 2011). In this section, we describe the findings of intervention studies that have coupled physical and cognitive demands.

5.1 In Children

Two explanations for the relationship between exercise and children's mental functioning have been offered: one focused on a quantitative approach, with exercise interventions based primarily on considerations of intensity and duration, and another, more qualitative, approach that manipulates physical activity in terms of the type of exercise and the cognitive abilities involved during movement (Pesce 2012). Based on the assumption that exercise directly affects brain health (Hillman et al. 2008), the majority of randomized controlled trials have focused on the manipulation of "dosage" (i.e., frequency, duration, and intensity). In these studies, various forms of aerobic exercise have been utilized to bring about changes in physical fitness as measured by cardiorespiratory capacity. Central to the quantitative approach is the notion that gains in cognitive function obtained from chronic exercise training would decay with reductions of the level of exercise activities.

From a qualitative perspective, it has been argued that interventions should focus on physical activities that include planning and problem solving, such as those involved in games or sport (Pesce 2012; Tomporowski et al. 2015). Through movement, it is hypothesized, individuals acquire knowledge about the actions that were performed, the consequences of those actions, and their context. Central to the qualitative approach is the assumption that executive functions can be enhanced with practice and experience, and that gains obtained from physical activity performed in complex environments will be maintained even as physical activity levels decline. Support for the benefits of mentally engaging physical activity interventions on cognitive function and learning has emerged over the past decade (Best 2010; Diamond and Lee 2011; Tomporowski et al. 2015). Drawing from contemporary motor-learning and rehabilitation research, greatest gains are achieved when tasks are based on the "optimal challenge point" hypothesis (Guadagnoli and Lee 2004), which posits that skill learning is facilitated when the skill level of the performer, the complexity of the task, and the task environment are taken into consideration. Convergent support comes from research that has examined the phenomena of contextual interference, which demonstrates superior motor and verbal learning when the order of training conditions are manipulated in ways that require an individual to vary the selection and execution of actions or mental processing from trial to trial (Tomporowski, McCullick, and Horvat 2010).

Maximizing the effects of physical activity interventions requires developing specific activities that are developmentally appropriate and cognitively and physically challenging, with target-specific outcome measures (Pesce 2012; Tomporowski et al. 2015). For example, younger children typically benefit from activities that are playful (Bjorklund and Brown 1998). Play includes activities that are freely chosen and intrinsically motivating and pleasurable. Children can engage in solitary play, parallel play, or cooperative play. During play, children are often engaged in make-believe and distortions of reality. As there are no exterior rules of play, children are provided the freedom to construct their own forms of reality. Play provides the opportunity to exercise and practice ways of physically and mentally altering the world. Children can construct, deconstruct, and reconstruct goal-directed activities (Scibinetti, Tocci, and Pesce 2011). Older children may benefit from game activities that are more structured and skill-based. As such, physical activity games are forms of competitive play characterized by established rules and set goals. Central to every game are challenges and obstacles to overcome. Indeed, successful games, whether they are video games, chess, or tag, are hallmarked by challenges that require very specific actions to be successful (Moreau 2015a; Tomporowski, McCullick, and Pesce 2015). As children's fundamental movement skills emerge, many children are introduced to sports, which are forms of competitive physical activity. Regardless of children's age, developmental level, and maturation, however, gains in cognitive outcomes hinge on involvement in sport or game conditions that place challenging, but manageable, problem-solving demands.

Successful interventions are characterized not only by the developmentally appropriate physical activity and exercise programs but also by the selection of outcome measures that are also developmentally appropriate and sensitive to change (Tomporowski 2009). The consensus drawn from recent comprehensive reviews of studies conducted with children, which examine the effects of chronic exercise and physical activity interventions on cognition and academic achievement, is that interventions influence specific mental process as opposed to exerting global widespread effects, such as general intelligence (Tomporowski, Naglieri, and Lambourne 2012).

5.2 In Young Adults

In contrast with early developmental stages, the potential for meaningful changes in the cognitive abilities of young adult populations was not fully recognized until recently. Young adults are usually thought to be at a cognitive peak (Salthouse and Davis 2006), thus leaving little room for improvement. Yet in recent years novel findings have shown that, although subtle, cognitive gains are still possible in adulthood. This line of work is rooted in decades of research showing the interrelation between motor processes and both spatial ability (Amorim, Isableu, and Jarraya 2006; Janczyk et al. 2012; Moreau 2012a; Steggemann, Engbert, and Weigelt 2011; Wraga et al. 2003) and working memory capacity (Moreau 2013), but also with language (Beilock et al. 2008), problem solving (Broaders et al. 2007), and reasoning (Beilock and Goldin-Meadow 2010; Cook, Mitchell, and Goldin-Meadow 2008). Corroborating evidence comes from studies of motor expertise, in which experts have been found to perform above average in assessments of perception (Wright et al. 2011), working memory capacity (Furley and Memmert 2010), attention (Memmert and Furley 2007), long-term memory (Dijkstra, MacMahon, and Misirlisoy 2008), and decision making (Raab and Johnson 2007).

Importantly, the implied directionality of these correlational findings has been confirmed by training studies, some of which have shown that forms of complex physical exercise trump more impoverished exercise workouts. Various approaches have been documented, including physical exercise, cognitive training, and hybrid forms of training (see, for a review, Moreau and Conway 2013). For example, wrestling, a sport that involves complex, unusual motor coordination, appears to elicit greater improvements in measures of spatial ability and working memory capacity than running, an activity largely automatized in adults (Moreau et al. 2012). We further replicated and extended these findings, with a training study that directly compared aerobic exercise, computerized cognitive training, and a hybrid condition we labeled *designed sport*, which combined high physical and cognitive demands in a single activity (Moreau, Morrison, and Conway 2015). Echoing the findings we described in the literature on children, we hypothesized that typical neurophysiological changes induced by exercise could be complemented by direct cognitive demands to maximize benefits. Not only did designed sport lead to larger cognitive gains in spatial ability and working memory capacity constructs, it also favored significant health improvements as measured by physiological markers such as resting heart rate and blood pressure. The holistic nature of these improvements confirmed our initial assumption: that is, complex motor activities are a potent way to elicit cognitive gains, with additional health benefits.

Crucially, one of the central points of this line of work is that designed sport can be adapted to individual affinities and demands, so that motivation and pleasure remain part of the equation. For example, there is extensive evidence that dance can be particularly well-adapted to cognitive training design, given the tremendous cognitive demands associated with the activity (Bläsing et al. 2012; Cross et al. 2013). Similarly, training simpler motor skills such as juggling has shown to induce gains in mental rotation performance (Lehmann and Jansen 2012), as does practicing sports or musical instruments, two types of activities including complex motor coordination (Moreau 2012b; Pietsch and Jansen 2012). Altogether, this body of evidence suggests that cognitive enhancement based on ecological activities might be preferable to so-called brain training programs, in the size and range of the effects (Moreau and Conway 2014).

5.3 In Older Adults

Because of the natural cognitive decline associated with age, older adult populations offer additional possibilities for enhancement. A large body of literature has looked at the impact of aerobic exercise interventions (Hertzog et al. 2008), for obvious reasons:

moderate-intensity exercise allows reducing risks of injury or cardiovascular complications, and such regimens are therefore more likely to obtain approval from medical and ethics boards. It is important to note, however, that the greater health safety of aerobic exercise interventions does not mean that they are the most suitable or the most optimal for everyone. When suitable, research to find alternative forms of exercise should be encouraged, so as to refine theoretical models of exercise-induced cognitive enhancement and to diversify the range of possibilities for consumers. Such studies are less common, but this body of work has been steadily growing over the past few years, and is expected to increase in the future.

Oftentimes, physical and cognitive components have been isolated and targeted in a sequential manner (Fabre et al. 2002; Legault et al. 2011; Oswald et al. 1996), with the advantages that implementation is typically easier, risks are restricted, and direct comparison of experimental conditions is more straightforward. Other forms of intervention have aimed at combining the two simultaneously (Eggenberger et al. 2015; Forte et al. 2013; Theill et al. 2013), with potential added improvements due to increased competition for cognitive resources. For example, a study by Eggenberger and colleagues found greater attention and working memory improvements after an intervention combining cognitive and physical components via distinct means than with physical exercise alone (Eggenberger et al. 2015).

Beyond the combination of separate tasks or activities, interventions that include adaptations of some form of complex motor activities have also been trialed, with encouraging results. For example, virtual reality videogames have been used to combine physical and cognitive training in single activities, setting the stage for a promising line of research (Pichierri et al. 2012; Pichierri, Murer, and de Bruin 2012).

Perhaps in a more ecological manner, a six-month dance intervention was found to enhance the cognitive performance of older adults, while no change was found in physiological markers of general health, thus suggesting that improvements were induced by motor demands, social engagement, or both, rather than by neurophysiological changes (Kattenstroth et al. 2013). Altogether, these findings are remarkably consistent with work in children (Pesce et al. 2016) and in young adults (Moreau, Morrison, and Conway 2015), further validating the rationale for a combined approach to maximize training outcomes (Moreau 2015a, 2015b).

6 Conclusion

The use of complex motor activities to enhance cognition is an exciting field of research with encouraging new developments. We have highlighted, throughout this chapter, some of the areas that have shown promising findings and applications. Although not exhaustive, the literature discussed herein provides solid grounds for understanding the mechanisms and the potential of this line of work.

We would like to leave the reader with a few thoughts, in the hope that these can stir the field in what we believe are interesting directions. First, it should be noted that blending training contents has potent implications, but also comes with challenges—it typically blurs the respective contribution of a given factor in an experimental design (Moreau, Kirk, and Waldie 2016). This in itself is not a valid argument against combinations of training regimens, but it emphasizes the need for additional research to correctly identify the underlying mechanisms and interactions of training-induced improvements. Research in this area will benefit from both tightly controlled but impoverished laboratory experiments and more-ecological but noisy interventions.

Second, whenever considering the implications of this line of research to society, one needs to consider opportunity costs, that is, what could I have done, as an individual, instead of training on a particular regimen. Not unlike current practices in pharmaceutical trials, where novel treatments need to demonstrate superiority over a placebo and over current drugs, if a given cognitive training program appears to be less effective than an existing regimen, its relevance should be questioned. The point is not to discourage novel interventions, as variety is critical to offer approaches suited to a wide range of individuals.

Yet one of the problems associated with computerized forms of cognitive training is that, despite dismissive attitudes toward potential risks of non-pharmaceutical or non-invasive interventions, the cost of ineffectiveness is high—if training improvements do not transfer to real-life abilities, time spent on the training regimen is wasted, and no useful skill or physiological by-product can be noted. The use of complex motor activities as a means of enhancing cognition is therefore appealing in that side effects are rewarding in and of themselves—improved physiological markers, general health, self-esteem, or stress reduction are hardly minimal outcomes (see, for a review, Moreau and Conway 2013). From there, risks are extremely mitigated, as time and effort invested in a program or an activity are more likely to be rewarded.

A challenge that remains, nevertheless, concerns the personalization of cognitive interventions. We now understand that not everyone will benefit equally from a given regimen, if at all, and therefore that finding the right intervention for an individual requires precise knowledge of the underlying mechanisms of improvement. Once cognitive training is based on sound and testable theoretical grounds, one can then envision apprehending enhancement probabilistically, with transparent information available to each individual regarding the likelihood and projected size of improvement. This is possibly the next frontier in the field of cognitive enhancement—individualized, dynamic, and information-rich content, so as to offer optimal interventions for everyone, at all times, in light of all the evidence available.

References

Amorim, Michel-Ange, Brice Isableu, and Mohamed Jarraya. 2006. "Embodied Spatial Transformations: 'Body Analogy' for the Mental Rotation of Objects." *Journal of Experimental Psychology: General* 135 (3): 327–347. doi:10.1037/0096-3445.135.3.327.

Amrein, Irmgard, and Hans-Peter Lipp. 2009. "Adult Hippocampal Neurogenesis of Mammals: Evolution and Life History." *Biology Letters* 5 (1): 141–144. doi:10.1098/rsbl.2008.0511.

Anderson, Megan L., Helene M. Sisti, Daniel M. Curlik II, and Tracey J. Shors. 2011. "Associative Learning Increases Adult Neurogenesis during a Critical Period." *European Journal of Neuroscience* 33 (1): 175–181. doi:10.1111/j.1460-9568.2010.07486.x.

Archer, Trevor, and Richard M. Kostrzewa. 2012. "Physical Exercise Alleviates ADHD Symptoms: Regional Deficits and Development Trajectory." *Neurotoxicity Research* 21 (2): 195–209. doi:10.1007/s12640-011-9260-0.

Arsenijevic, Yvan, and Samuel Weiss. 1998. "Insulin-Like Growth Factor-I Is a Differentiation Factor for Postmitotic CNS Stem Cell-Derived Neuronal Precursors: Distinct Actions from Those of Brain-Derived Neurotrophic Factor." *Journal of Neuroscience* 18 (6): 2118–2128.

Au, J., E. Sheehan, N. Tsai, G. J. Duncan, M. Buschkuehl, and S. M. Jaeggi. 2014. "Improving Fluid Intelligence with Training on Working Memory: A Meta-analysis." *Psychonomic Bulletin & Review* 22 (2): 366–377. http://doi.org/10.3758/s13423-014-0699-x.

Barsalou, Lawrence W. 2008. "Grounded Cognition." *Annual Review of Psychology* 59:617–645. doi:10.1146/annurev.psych.59.103006.093639.

Beilock, S. L., and S. Goldin-Meadow. 2010. "Gesture Changes Thought by Grounding It in Action." *Psychological Science* 21 (11): 1605–1610. doi:10.1177/0956797610385353.

Beilock, Sian L., Ian M. Lyons, Andrew Mattarella-Micke, Howard C. Nusbaum, and Steven L. Small. 2008. "Sports Experience Changes the Neural Processing of Action Language." *Proceedings of the National Academy of Sciences of the United States of America* 105 (36): 13269–13273. doi:10.1073/pnas.0803424105.

Ben-Soussan, Tal Dotan, Joseph Glicksohn, and Aviva Berkovich-Ohana. 2015. "From Cerebellar Activation and Connectivity to Cognition: A Review of the Quadrato Motor Training." *BioMed Research International* 2015 (October): 954901. doi:10.1155/2015/954901.

Berchtold, Nicole C., J. Patrick Kesslak, Christian J. Pike, Paul A. Adlard, and Carl W. Cotman. 2001. "Estrogen and Exercise Interact to Regulate Brain-Derived Neurotrophic Factor mRNA and Protein Expression in the Hippocampus." *European Journal of Neuroscience* 14 (12): 1992–2002.

Best, John R. 2010. "Effects of Physical Activity on Children's Executive Function: Contributions of Experimental Research on Aerobic Exercise." *Developmental Review* 30 (4): 331–551.

Bilello, Michel, Jimit Doshi, S. Ali Nabavizadeh, Jon B. Toledo, Guray Erus, Sharon X. Xie, John Q. Trojanowski, Xiaoyan Han, and Christos Davatzikos. 2015. "Correlating Cognitive Decline with White Matter Lesion and Brain Atrophy Magnetic Resonance Imaging Measurements in Alzheimer's Disease." *Journal of Alzheimer's Disease* 48 (4): 987–994. doi:10.3233/JAD-150400.

Bjorklund, D. F., and R. D. Brown. 1998. "Physical Play and Cognitive Development: Integrating Activity, Cognition, and Education." *Child Development* 69 (3): 604–606.

Black, J. E., K. R. Isaacs, B. J. Anderson, A. A. Alcantara, and W. T. Greenough. 1990. "Learning Causes Synaptogenesis, Whereas Motor Activity Causes Angiogenesis, in Cerebellar Cortex of Adult Rats." *Proceedings of the National Academy of Sciences of the United States of America* 87 (14): 5568–5572.

Bläsing, Bettina, Beatriz Calvo-Merino, Emily S. Cross, Corinne Jola, Juliane Honisch, and Catherine J. Stevens. 2012. "Neurocognitive Control in Dance Perception and Performance." *Acta Psychologica* 139 (2): 300–308. doi:10.1016/j.actpsy.2011.12.005.

Blumenthal, J. A., C. F. Emery, D. J. Madden, S. Schniebolk, M. Walsh-Riddle, L. K. George, D. C. McKee, M. B. Higginbotham, F. R. Cobb, and R. E. Coleman. 1991. "Long-Term Effects of Exercise on Psychological Functioning in Older Men and Women." *Journal of Gerontology* 46 (6): P352–361.

Boström, Pontus, Jun Wu, Mark P. Jedrychowski, Anisha Korde, Li Ye, James C. Lo, Kyle A. Rasbach, et al. 2012. "A PGC1-α-Dependent Myokine That Drives Brown-Fat-like Development of White Fat and Thermogenesis." *Nature* 481 (7382): 463–468. doi:10.1038/nature10777.

Broaders, Sara C., Susan Wagner Cook, Zachary Mitchell, and Susan Goldin-Meadow. 2007. "Making Children Gesture Brings out Implicit Knowledge and Leads to Learning." *Journal of Experimental Psychology: General* 136 (4): 539–550. doi:10.1037/0096-3445.136.4.539.

Caeyenberghs, Karen, Claudia Metzler-Baddeley, Sonya Foley, and Derek K. Jones. 2016. "Dynamics of the Human Structural Connectome Underlying Working Memory Training." *Journal of Neuroscience* 36 (14): 4056–4066. doi:10.1523/JNEUROSCI.1973-15.2016.

Cancela Carral, J. M., and Carlos Ayán Pérez. 2007. "Effects of High-Intensity Combined Training on Women over 65." *Gerontology* 53 (6): 340–346.

Castelli, Darla M., Charles H. Hillman, Sarah M. Buck, and Heather E. Erwin. 2007. "Physical Fitness and Academic Achievement in Third- and Fifth-Grade Students." *Journal of Sport and Exercise Psychology* 29 (2): 239–252.

Chaddock-Heyman, Laura, Kirk I. Erickson, Joseph L. Holtrop, Michelle W. Voss, Matthew B. Pontifex, Lauren B. Raine, Charles H. Hillman, and Arthur F. Kramer. 2014. "Aerobic Fitness Is Associated with Greater White Matter Integrity in Children." *Frontiers in Human Neuroscience* 8 (August): 584. doi:10.3389/fnhum.2014.00584.

Chaddock-Heyman, Laura, Kirk I. Erickson, Michelle W. Voss, Anya M. Knecht, Matthew B. Pontifex, Darla M. Castelli, Charles H. Hillman, and Arthur F. Kramer. 2013. "The Effects of Physical

Activity on Functional MRI Activation Associated with Cognitive Control in Children: A Randomized Controlled Intervention." *Frontiers in Human Neuroscience* 7 (March): 72. doi:10.3389/fnhum.2013.00072.

Chen, Dillon Y., Sarah A. Stern, Ana Garcia-Osta, Bernadette Saunier-Rebori, Gabriella Pollonini, Dhananjay Bambah-Mukku, Robert D. Blitzer, and Cristina M. Alberini. 2011. "A Critical Role for IGF-II in Memory Consolidation and Enhancement." *Nature* 469 (7331): 491–497. doi:10.1038/nature09667.

Coe, Dawn Podulka, James M. Pivarnik, Christopher J. Womack, Mathew J. Reeves, and Robert M. Malina. 2006. "Effect of Physical Education and Activity Levels on Academic Achievement in Children." *Medicine and Science in Sports and Exercise* 38 (8): 1515–1519. doi:10.1249/01.mss.0000227537.13175.1b.

Colcombe, Stanley, and Arthur F. Kramer. 2003. "Fitness Effects on the Cognitive Function of Older Adults: A Meta-Analytic Study." *Psychological Science* 14 (2): 125–130.

Colcombe, Stanley J., Kirk I. Erickson, Naftali Raz, Andrew G. Webb, Neal J. Cohen, Edward McAuley, and Arthur F. Kramer. 2003. "Aerobic Fitness Reduces Brain Tissue Loss in Aging Humans." *Journals of Gerontology A: Biological Sciences and Medical Sciences* 58 (2): 176–180.

Colcombe, Stanley J., Kirk I. Erickson, Paige E. Scalf, Jenny S. Kim, Ruchika Prakash, Edward McAuley, Steriani Elavsky, David X. Marquez, Liang Hu, and Arthur F. Kramer. 2006. "Aerobic Exercise Training Increases Brain Volume in Aging Humans." *Journals of Gerontology A: Biological Sciences and Medical Sciences* 61 (11): 1166–1170.

Cook, Susan Wagner, Zachary Mitchell, and Susan Goldin-Meadow. 2008. "Gesturing Makes Learning Last." *Cognition* 106 (2): 1047–1058. doi:10.1016/j.cognition.2007.04.010.

Cotman, Carl W., and Nicole C. Berchtold. 2002. "Exercise: A Behavioral Intervention to Enhance Brain Health and Plasticity." *Trends in Neurosciences* 25 (6): 295–301.

Cross, Emily S., Waltraud Stadler, Jim Parkinson, Simone Schütz-Bosbach, and Wolfgang Prinz. 2013. "The Influence of Visual Training on Predicting Complex Action Sequences." *Human Brain Mapping* 34 (2): 467–486. doi:10.1002/hbm.21450.

Curlik, D. M. II, and T. J. Shors. 2013. "Training Your Brain: Do Mental and Physical (MAP) Training Enhance Cognition through the Process of Neurogenesis in the Hippocampus?" *Neuropharmacology* 64 (January): 506–514. doi:10.1016/j.neuropharm.2012.07.027.

Curlik, Daniel M. II, Lisa Y. Maeng, Prateek R. Agarwal, and Tracey J. Shors. 2013. "Physical Skill Training Increases the Number of Surviving New Cells in the Adult Hippocampus." *PLoS ONE* 8 (2): e55850. doi:10.1371/journal.pone.0055850.

Curlik, Daniel M. II, and Tracey J. Shors. 2011. "Learning Increases the Survival of Newborn Neurons Provided That Learning Is Difficult to Achieve and Successful." *Journal of Cognitive Neuroscience* 23 (9): 2159–2170. doi:10.1162/jocn.2010.21597.

Davis, Catherine L., Phillip D. Tomporowski, Colleen A. Boyle, Jennifer L. Waller, Patricia H. Miller, Jack A. Naglieri, and Mathew Gregoski. 2007. "Effects of Aerobic Exercise on Overweight

Children's Cognitive Functioning: A Randomized Controlled Trial." *Research Quarterly for Exercise and Sport* 78 (5): 510–519. doi:10.1080/02701367.2007.10599450.

Davis, Catherine L., Phillip D. Tomporowski, Jennifer E. McDowell, Benjamin P. Austin, Patricia H. Miller, Nathan E. Yanasak, Jerry D. Allison, and Jack A. Naglieri. 2011. "Exercise Improves Executive Function and Achievement and Alters Brain Activation in Overweight Children: A Randomized, Controlled Trial." *Health Psychology* 30 (1): 91–98. doi:10.1037/a0021766.

de Lange, Floris P., Karin Roelofs, and Ivan Toni. 2008. "Motor Imagery: A Window into the Mechanisms and Alterations of the Motor System." *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior* 44 (5): 494–506. doi:10.1016/j.cortex.2007.09.002.

Diamond, A. 2000. "Close Interrelation of Motor Development and Cognitive Development and of the Cerebellum and Prefrontal Cortex." *Child Development* 71 (1): 44–56.

Diamond, Adele. 2013. "Executive Functions." *Annual Review of Psychology* 64: 135–168. doi:10.1146/annurev-psych-113011-143750.

Diamond, Adele, and Kathleen Lee. 2011. "Interventions Shown to Aid Executive Function Development in Children 4 to 12 Years Old." *Science* 333 (6045): 959–964. doi:10.1126/science.1204529.

Dijkstra, Katinka, Clare MacMahon, and Mine Misirlisoy. 2008. "The Effects of Golf Expertise and Presentation Modality on Memory for Golf and Everyday Items." *Acta Psychologica* 128 (2): 298–303. doi:10.1016/j.actpsy.2008.03.001.

Donnelly, Joseph E., Charles H. Hillman, Darla Castelli, Jennifer L. Etnier, Sarah Lee, Phillip Tomporowski, Kate Lambourne, and Amanda N. Szabo-Reed. 2016. "Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review." *Medicine and Science in Sports and Exercise* 48 (6): 1197–1222.

Dove, Guy. 2010. "On the Need for Embodied and Dis-Embodied Cognition." *Frontiers in Psychology* 1:242. doi:10.3389/fpsyg.2010.00242.

Eggenberger, Patrick, Vera Schumacher, Marius Angst, Nathan Theill, and Eling D. de Bruin. 2015. "Does Multicomponent Physical Exercise with Simultaneous Cognitive Training Boost Cognitive Performance in Older Adults? A 6-Month Randomized Controlled Trial with a 1-Year Follow-Up." *Clinical Interventions in Aging* 10 (August): 1335–1349. doi:10.2147/CIA.S87732.

Erickson, Kirk I., Ruchika S. Prakash, Michelle W. Voss, Laura Chaddock, Liang Hu, Katherine S. Morris, Siobhan M. White, Thomas R. Wójcicki, Edward McAuley, and Arthur F. Kramer. 2009. "Aerobic Fitness Is Associated with Hippocampal Volume in Elderly Humans." *Hippocampus* 19 (10): 1030–1039. doi:10.1002/hipo.20547.

Erickson, Kirk I., Michelle W. Voss, Ruchika Shaurya Prakash, Chandramallika Basak, Amanda Szabo, Laura Chaddock, Jennifer S. Kim, et al. 2011. "Exercise Training Increases Size of Hippocampus and Improves Memory." *Proceedings of the National Academy of Sciences of the United States of America* 108 (7): 3017–3022. doi:10.1073/pnas.1015950108.

Ericsson, K. Anders, Ralf T. Krampe, and Clemens Tesch-Römer. 1993. "The Role of Deliberate Practice in the Acquisition of Expert Performance." *Psychological Review* 100 (3): 363–406.

Fabre, C., K. Chamari, P. Mucci, J. Massé-Biron, and C. Préfaut. 2002. "Improvement of Cognitive Function by Mental and/or Individualized Aerobic Training in Healthy Elderly Subjects." *International Journal of Sports Medicine* 23 (6): 415–421. doi:10.1055/s-2002-33735.

Ferris, Lee T., James S. Williams, and Chwan-Li Shen. 2007. "The Effect of Acute Exercise on Serum Brain-Derived Neurotrophic Factor Levels and Cognitive Function." *Medicine and Science in Sports and Exercise* 39 (4): 728–734. doi:10.1249/mss.0b013e31802f04c7.

Forte, Roberta, Colin A. G. Boreham, João Costa Leite, Giuseppe De Vito, Lorraine Brennan, Eileen R. Gibney, and Caterina Pesce. 2013. "Enhancing Cognitive Functioning in the Elderly: Multicomponent vs Resistance Training." *Clinical Interventions in Aging* 8 (January): 19–27. doi:10.2147/CIA.S36514.

Furley, Philip, and Daniel Memmert. 2010. "Differences in Spatial Working Memory as a Function of Team Sports Expertise: The Corsi Block-Tapping Task in Sport Psychological Assessment." *Perceptual and Motor Skills* 110 (3 Pt 1): 801–808. doi:10.2466/PMS.110.3.801-808.

Gallese, V. 1998. "Mirror Neurons and the Simulation Theory of Mind-Reading." *Trends in Cognitive Sciences* 2 (12): 493–501. doi:10.1016/S1364-6613(98)01262-5.

Gallese, Vittorio, and Corrado Sinigaglia. 2011. "What Is So Special about Embodied Simulation?" *Trends in Cognitive Sciences* 15 (11): 512–519. doi:10.1016/j.tics.2011.09.003.

Glenberg, Arthur M. 2010. "Embodiment as a Unifying Perspective for Psychology." *Wiley Interdisciplinary Reviews: Cognitive Science* 1 (4): 586–596. doi:10.1002/wcs.55.

Gould, E., A. Beylin, P. Tanapat, A. Reeves, and T. J. Shors. 1999. "Learning Enhances Adult Neurogenesis in the Hippocampal Formation." *Nature Neuroscience* 2 (3): 260–265. doi:10.1038/6365.

Gould, E., C. S. Woolley, M. Frankfurt, and B. S. McEwen. 1990. "Gonadal Steroids Regulate Dendritic Spine Density in Hippocampal Pyramidal Cells in Adulthood." *Journal of Neuroscience* 10 (4): 1286–1291.

Griffin, Éadaoin W., Sinéad Mullally, Carole Foley, Stuart A. Warmington, Shane M. O'Mara, and Aine M. Kelly. 2011. "Aerobic Exercise Improves Hippocampal Function and Increases BDNF in the Serum of Young Adult Males." *Physiology and Behavior* 104 (5): 934–941. doi:10.1016/j.physbeh.2011.06.005.

Guadagnoli, Mark A., and Timothy D. Lee. 2004. "Challenge Point: A Framework for Conceptualizing the Effects of Various Practice Conditions in Motor Learning." *Journal of Motor Behavior* 36 (2): 212–224. doi:10.3200/JMBR.36.2.212-224.

Güldenpenning, Iris, Dirk Koester, Wilfried Kunde, Matthias Weigelt, and Thomas Schack. 2011. "Motor Expertise Modulates the Unconscious Processing of Human Body Postures." *Experimental Brain Research* 213 (4): 383–391. doi:10.1007/s00221-011-2788-7.

Harrison, Tyler L., Zach Shipstead, Kenny L. Hicks, David Z. Hambrick, Thomas S. Redick, and Randall W. Engle. 2013. “Working Memory Training May Increase Working Memory Capacity but Not Fluid Intelligence.” *Psychological Science* 24 (12): 2409–2419. doi:10.1177/0956797613492984.

Hertzog, Christopher, Arthur F. Kramer, Robert S. Wilson, and Ulman Lindenberger. 2008. “Enrichment Effects on Adult Cognitive Development: Can the Functional Capacity of Older Adults Be Preserved and Enhanced?” *Psychological Science in the Public Interest* 9 (1): 1–65. doi:10.1111/j.1539-6053.2009.01034.x.

Hickok, G. 2009. “Eight Problems for the Mirror Neuron Theory of Action Understanding in Monkeys and Humans.” *Journal of Cognitive Neuroscience* 21 (7): 1229–1243. doi:10.1162/jocn.2009.21189.

Hillman, Charles H., Kirk I. Erickson, and Arthur F. Kramer. 2008. “Be Smart, Exercise Your Heart: Exercise Effects on Brain and Cognition.” *Nature Reviews: Neuroscience* 9 (1): 58–65. doi:10.1038/nrn2298.

Hillman, Charles H., Matthew B. Pontifex, Darla M. Castelli, Naiman A. Khan, Lauren B. Raine, Mark R. Scudder, Eric S. Drollette, Robert D. Moore, Chien-Ting Wu, and Keita Kamijo. 2014. “Effects of the FITKids Randomized Controlled Trial on Executive Control and Brain Function.” *Pediatrics* 134 (4): e1063–1071. doi:10.1542/peds.2013-3219.

Holt, Lauren E., and Sian L. Beilock. 2006. “Expertise and Its Embodiment: Examining the Impact of Sensorimotor Skill Expertise on the Representation of Action-Related Text.” *Psychonomic Bulletin and Review* 13 (4): 694–701.

Hovik, Kjell Tore, Brit-Kari Saunes, Anne Kristine Aarlien, and Jens Egeland. 2013. “RCT of Working Memory Training in ADHD: Long-Term Near-Transfer Effects.” *PLoS ONE* 8 (12): e80561. doi:10.1371/journal.pone.0080561.

Huat, Tee Jong, Amir Ali Khan, Soumya Pati, Zulkifli Mustafa, Jafri Malin Abdullah, and Hasnan Jaafar. 2014. “IGF-1 Enhances Cell Proliferation and Survival during Early Differentiation of Mesenchymal Stem Cells to Neural Progenitor-like Cells.” *BMC Neuroscience* 15 (July): 91. doi:10.1186/1471-2202-15-91.

Jaeggi, Susanne M., Martin Buschkuehl, John Jonides, and Walter J. Perrig. 2008. “Improving Fluid Intelligence with Training on Working Memory.” *Proceedings of the National Academy of Sciences of the United States of America* 105 (19): 6829–6833. doi:10.1073/pnas.0801268105.

Jaeggi, Susanne M., Martin Buschkuehl, John Jonides, and Priti Shah. 2011. “Short- and Long-Term Benefits of Cognitive Training.” *Proceedings of the National Academy of Sciences of the United States of America* 108 (25): 10081–10086. doi:10.1073/pnas.1103228108.

Jaeggi, Susanne M., Martin Buschkuehl, Priti Shah, and John Jonides. 2014. “The Role of Individual Differences in Cognitive Training and Transfer.” *Memory and Cognition* 42 (3): 464–480. doi:10.3758/s13421-013-0364-z.

James, W. [1890] 1981. *The Principles of Psychology*. Cambridge, MA: Harvard University Press.

Janczyk, Markus, Roland Pfister, Michael A. Crognale, and Wilfried Kunde. 2012. “Effective Rotations: Action Effects Determine the Interplay of Mental and Manual Rotations.” *Journal of Experimental Psychology: General* 141 (3): 489–501.

Jeannerod, M. 2001. “Neural Simulation of Action: A Unifying Mechanism for Motor Cognition.” *NeuroImage* 14 (1 Pt 2): S103–109. doi:10.1006/nimg.2001.0832.

Jeannerod, M., and J. Decety. 1995. “Mental Motor Imagery: A Window into the Representational Stages of Action.” *Current Opinion in Neurobiology* 5 (6): 727–732.

Kamijo, Keita, Matthew B. Pontifex, Kevin C. O’Leary, Mark R. Scudder, Chien-Ting Wu, Darla M. Castelli, and Charles H. Hillman. 2011. “The Effects of an Afterschool Physical Activity Program on Working Memory in Preadolescent Children.” *Developmental Science* 14 (5): 1046–1058. doi:10.1111/j.1467-7687.2011.01054.x.

Kattenstroth, Jan-Christoph, Tobias Kalisch, Stephan Holt, Martin Tegenthoff, and Hubert R. Dinse. 2013. “Six Months of Dance Intervention Enhances Postural, Sensorimotor, and Cognitive Performance in Elderly without Affecting Cardio-Respiratory Functions.” *Frontiers in Aging Neuroscience* 5 (February): 5. doi:10.3389/fnagi.2013.00005.

Keeley, Thomas J. H., and Kenneth R. Fox. 2009. “The Impact of Physical Activity and Fitness on Academic Achievement and Cognitive Performance in Children.” *International Review of Sport and Exercise Psychology* 2 (2): 198–214. doi:10.1080/17509840903233822.

Kempermann, Gerd, Laurenz Wiskott, and Fred H. Gage. 2004. “Functional Significance of Adult Neurogenesis.” *Current Opinion in Neurobiology* 14 (2): 186–191. doi:10.1016/j.conb.2004.03.001.

Kooistra, Minke, Mirjam I. Geerlings, Yolanda van der Graaf, Willem P. T. M. Mali, Koen L. Vincken, L. Jaap Kappelle, Majon Muller, Geert Jan Biessels, and SMART-MR Study Group. 2014. “Vascular Brain Lesions, Brain Atrophy, and Cognitive Decline. The Second Manifestations of ARTerial Disease—Magnetic Resonance (SMART-MR) Study.” *Neurobiology of Aging* 35 (1): 35–41. doi:10.1016/j.neurobiolaging.2013.07.004.

Krafft, Cynthia E., Nicolette F. Schwarz, Lingxi Chi, Abby L. Weinberger, David J. Schaeffer, Jordan E. Pierce, Amanda L. Rodrigue, et al. 2014. “An 8-Month Randomized Controlled Exercise Trial Alters Brain Activation during Cognitive Tasks in Overweight Children.” *Obesity* 22 (1): 232–242. doi:10.1002/oby.20518.

Kramer, A. F., S. Hahn, and D. Gopher. 1999. “Task Coordination and Aging: Explorations of Executive Control Processes in the Task Switching Paradigm.” *Acta Psychologica* 101 (2/3): 339–378.

Lampit, Amit, Harry Hallock, and Michael Valenzuela. 2014. “Computerized Cognitive Training in Cognitively Healthy Older Adults: A Systematic Review and Meta-Analysis of Effect Modifiers.” *PLoS Medicine* 11 (11): e1001756. doi:10.1371/journal.pmed.1001756.

Legault, Claudine, Janine M. Jennings, Jeffrey A. Katula, Dale Dagenbach, Sarah A. Gaussoin, Kaycee M. Sink, Stephen R. Rapp, et al. 2011. “Designing Clinical Trials for Assessing the Effects of Cognitive Training and Physical Activity Interventions on Cognitive Outcomes: The Seniors

Health and Activity Research Program Pilot (SHARP-P) Study, a Randomized Controlled Trial." *BMC Geriatrics* 11 (May): 27. doi:10.1186/1471-2318-11-27.

Lehmann, Jennifer, and Petra Jansen. 2012. "The Influence of Juggling on Mental Rotation Performance in Children with Spina Bifida." *Brain and Cognition* 80 (2): 223–229. doi:10.1016/j.bandc.2012.07.004.

Leiner, H. C., A. L. Leiner, and R. S. Dow. 1986. "Does the Cerebellum Contribute to Mental Skills?" *Behavioral Neuroscience* 100 (4): 443–454.

Leiner, H. C., A. L. Leiner, and R. S. Dow. 1989. "Reappraising the Cerebellum: What Does the Hindbrain Contribute to the Forebrain?" *Behavioral Neuroscience* 103 (5): 998–1008.

Leiner, H. C., A. L. Leiner, and R. S. Dow. 1993. "The Role of the Cerebellum in the Human Brain." *Trends in Neurosciences* 16 (11): 453–454. doi:10.1016/0166-2236(93)90076-X.

Leuner, Bendetta, Sabrina Mendolia-Loffredo, Yevgenia Kozorovitskiy, Deanna Samburg, Elizabeth Gould, and Tracey J. Shors. 2004. "Learning Enhances the Survival of New Neurons beyond the Time When the Hippocampus Is Required for Memory." *Journal of Neuroscience* 24 (34): 7477–7481. doi:10.1523/JNEUROSCI.0204-04.2004.

Makizako, Hyuma, Teresa Liu-Ambrose, Hiroyuki Shimada, Takehiko Doi, Hyuntae Park, Kota Tsutsumimoto, Kazuki Uemura, and Takao Suzuki. 2015. "Moderate-Intensity Physical Activity, Hippocampal Volume, and Memory in Older Adults with Mild Cognitive Impairment." *Journals of Gerontology A: Biological Sciences and Medical Sciences* 70 (4): 480–486. doi:10.1093/gerona/glu136.

Melby-Lervåg, Monica, and Charles Hulme. 2013. "Is Working Memory Training Effective? A Meta-Analytic Review." *Developmental Psychology* 49 (2): 270–291. doi:10.1037/a0028228.

Memmert, Daniel, and Philip Furley. 2007. "'I Spy with My Little Eye!': Breadth of Attention, Inattentional Blindness, and Tactical Decision Making in Team Sports." *Journal of Sport and Exercise Psychology* 29 (3): 365–381.

Miyake, Akira, Naomi P. Friedman, Michael J. Emerson, Alexander H. Witzki, Amy Howerter, and Tor D. Wager. 2000. "The Unity and Diversity of Executive Functions and Their Contributions to Complex 'Frontal Lobe' Tasks: A Latent Variable Analysis." *Cognitive Psychology* 41 (1): 49–100. doi:10.1006/cogp.1999.0734.

Mora, Francisco, Gregorio Segovia, and Alberto del Arco. 2007. "Aging, Plasticity and Environmental Enrichment: Structural Changes and Neurotransmitter Dynamics in Several Areas of the Brain." *Brain Research Reviews* 55 (1): 78–88. doi:10.1016/j.brainresrev.2007.03.011.

Moreau, David. 2012a. "The Role of Motor Processes in Three-Dimensional Mental Rotation: Shaping Cognitive Processing via Sensorimotor Experience." *Learning and Individual Differences* 22 (3): 354–359.

Moreau, David. 2012b. "Training Spatial Ability: Comment on Pietsch and Jansen (2012) and Prospective Research Trends." *Learning and Individual Differences* 22 (6): 882–883. doi:10.1016/j.lindif.2012.07.006.

Moreau, David. 2013. “Motor Expertise Modulates Movement Processing in Working Memory.” *Acta Psychologica* 142 (3): 356–361.

Moreau, David. 2014. “Making Sense of Discrepancies in Working Memory Training Experiments: A Monte Carlo Simulation.” *Frontiers in Systems Neuroscience* 8 (September): 161. doi:10.3389/fnsys.2014.00161.

Moreau, David. 2015a. “Unreflective Actions? Complex Motor Skill Acquisition to Enhance Spatial Cognition.” *Phenomenology and the Cognitive Sciences* 14 (2): 349–359. doi:10.1007/s11097-014-9376-9.

Moreau, David. 2015b. “Brains and Brawn: Complex Motor Activities to Maximize Cognitive Enhancement.” *Educational Psychology Review* 27 (3): 475–482. doi:10.1007/s10648-015-9323-5.

Moreau, David, Jérome Clerc, Annie Mansy-Dannay, and Alain Guerrien. 2012. “Enhancing Spatial Ability through Sport Practice: Evidence for an Effect of Motor Training on Mental Rotation Performance.” *Journal of Individual Differences* 33 (2): 83–88. doi:10.1027/1614-0001/a000075.

Moreau, David, and Andrew R. A. Conway. 2013. “Cognitive Enhancement: A Comparative Review of Computerized and Athletic Training Programs.” *International Review of Sport and Exercise Psychology* 6 (1): 155–183. doi:10.1080/1750984X.2012.758763.

Moreau, David, and Andrew R. A. Conway. 2014. “The Case for an Ecological Approach to Cognitive Training.” *Trends in Cognitive Sciences* 18 (7): 334–336. doi:10.1016/j.tics.2014.03.009.

Moreau, David, Ian J. Kirk, and Karen E. Waldie. 2016. “Seven Pervasive Statistical Flaws in Cognitive Training Interventions.” *Frontiers in Human Neuroscience* 10 (April): 153.

Moreau, David, Alexandra B. Morrison, and Andrew R. A. Conway. 2015. “An Ecological Approach to Cognitive Enhancement: Complex Motor Training.” *Acta Psychologica* 157 (May): 44–55. doi:10.1016/j.actpsy.2015.02.007.

Moreau, David, and Karen E. Waldie. 2016. “Developmental Learning Disorders: From Generic Interventions to Individualized Remediation.” *Frontiers in Psychology* 6:2053. doi:10.3389/fpsyg.2015.02053.

Neeper, S. A., F. Gómez-Pinilla, J. Choi, and C. Cotman. 1995. “Exercise and Brain Neurotrophins.” *Nature* 373 (6510): 109. doi:10.1038/373109a0.

Neeper, S. A., F. Gómez-Pinilla, J. Choi, and C. W. Cotman. 1996. “Physical Activity Increases mRNA for Brain-Derived Neurotrophic Factor and Nerve Growth Factor in Rat Brain.” *Brain Research* 726 (1/2): 49–56.

Nokia, Miriam S., Helene M. Sisti, Monica R. Choksi, and Tracey J. Shors. 2012. “Learning to Learn: Theta Oscillations Predict New Learning, Which Enhances Related Learning and Neurogenesis.” *PLoS ONE* 7 (2): e31375. doi:10.1371/journal.pone.0031375.

Oswald, W. D., R. Rupprecht, T. Gunzelmann, and K. Tritt. 1996. “The SIMA-Project: Effects of 1 Year Cognitive and Psychomotor Training on Cognitive Abilities of the Elderly.” *Behavioural Brain Research* 78 (1): 67–72.

Oztop, Erhan, Mitsuo Kawato, and Michael Arbib. 2006. "Mirror Neurons and Imitation: A Computationally Guided Review." *Neural Networks* 19 (3): 254–271. doi:10.1016/j.neunet.2006.02.002.

Penedo, Frank J., and Jason R. Dahn. 2005. "Exercise and Well-Being: A Review of Mental and Physical Health Benefits Associated with Physical Activity." *Current Opinion in Psychiatry* 18 (2): 189–193.

Pesce, Caterina. 2012. "Shifting the Focus from Quantitative to Qualitative Exercise Characteristics in Exercise and Cognition Research." *Journal of Sport and Exercise Psychology* 34 (6): 766–786.

Pesce, Caterina, Ilaria Masci, Rosalba Marchetti, Spyridoula Vazou, Arja Sääkslahti, and Phillip D. Tomporowski. 2016. "Deliberate Play and Preparation Jointly Benefit Motor and Cognitive Development: Mediated and Moderated Effects." *Frontiers in Psychology* 7 (March): 349. doi:10.3389/fpsyg.2016.00349.

Pichierri, Giuseppe, Amos Coppe, Silvio Lorenzetti, Kurt Murer, and Eling D. de Bruin. 2012. "The Effect of a Cognitive-Motor Intervention on Voluntary Step Execution under Single and Dual Task Conditions in Older Adults: A Randomized Controlled Pilot Study." *Clinical Interventions in Aging* 7 (July): 175–184. doi:10.2147/CIA.S32558.

Pichierri, Giuseppe, Kurt Murer, and Eling D. de Bruin. 2012. "A Cognitive-Motor Intervention Using a Dance Video Game to Enhance Foot Placement Accuracy and Gait under Dual Task Conditions in Older Adults: A Randomized Controlled Trial." *BMC Geriatrics* 12 (December): 74. doi:10.1186/1471-2318-12-74.

Pietsch, Stefanie, and Petra Jansen. 2012/2. "Different Mental Rotation Performance in Students of Music, Sport and Education." *Learning and Individual Differences* 22 (1): 159–163. doi:10.1016/j.lindif.2011.11.012.

Praag, H., G. Kempermann, and F. H. Gage. 1999. "Running Increases Cell Proliferation and Neurogenesis in the Adult Mouse Dentate Gyrus." *Nature Neuroscience* 2 (3): 266–270. doi:10.1038/6368.

Praag, Henriette, Alejandro F. Schinder, Brian R. Christie, Nicolas Toni, Theo D. Palmer, and Fred H. Gage. 2002. "Functional Neurogenesis in the Adult Hippocampus." *Nature* 415 (6875): 1030–1034. doi:10.1038/4151030a.

Raab, Markus, and Joseph G. Johnson. 2007. "Expertise-Based Differences in Search and Option-Generation Strategies." *Journal of Experimental Psychology: Applied* 13 (3): 158–170. doi:10.1037/1076-898X.13.3.158.

Rakic, P. 1985. "Limits of Neurogenesis in Primates." *Science* 227 (4690): 1054–1056.

Redick, Thomas S., Zach Shipstead, Tyler L. Harrison, Kenny L. Hicks, David E. Fried, David Z. Hambrick, Michael J. Kane, and Randall W. Engle. 2013. "No Evidence of Intelligence Improvement after Working Memory Training: A Randomized, Placebo-Controlled Study." *Journal of Experimental Psychology: General* 142 (2): 359–379. doi:10.1037/a0029082.

Rizzolatti, Giacomo, and Laila Craighero. 2004. "The Mirror-Neuron System." *Annual Review of Neuroscience* 27:169–192. doi:10.1146/annurev.neuro.27.070203.144230.

Rudebeck, Sarah R., Daniel Bor, Angharad Ormond, Jill X. O'Reilly, and Andy C. H. Lee. 2012. "A Potential Spatial Working Memory Training Task to Improve Both Episodic Memory and Fluid Intelligence." *PLoS ONE* 7 (11): e50431. doi:10.1371/journal.pone.0050431.

Ruscheweyh, R., C. Willemer, K. Krüger, T. Duning, T. Warnecke, J. Sommer, K. Völker, et al. 2011. "Physical Activity and Memory Functions: An Interventional Study." *Neurobiology of Aging* 32 (7): 1304–1319. doi:10.1016/j.neurobiolaging.2009.08.001.

Russo-Neustadt, Amelia, Tony Ha, Ronald Ramirez, and J. Patrick Kesslak. 2001. "Physical Activity–Antidepressant Treatment Combination: Impact on Brain-Derived Neurotrophic Factor and Behavior in an Animal Model." *Behavioural Brain Research* 120 (1): 87–95.

Salthouse, Timothy A., and Hasker P. Davis. 2006. "Organization of Cognitive Abilities and Neuropsychological Variables across the Lifespan." *Developmental Review* 26 (1): 31–54. doi:10.1016/j.dr.2005.09.001.

Schaeffer, David J., Cynthia E. Krafft, Nicolette F. Schwarz, Lingxi Chi, Amanda L. Rodrigue, Jordan E. Pierce, Jerry D. Allison, et al. 2014. "An 8-Month Exercise Intervention Alters Frontotemporal White Matter Integrity in Overweight Children." *Psychophysiology* 51 (8): 728–733. doi:10.1111/psyp.12227.

Schmidt, Richard A., and Craig A. Wrisberg. 2008. *Motor Learning and Performance: A Situation-Based Learning Approach*. Champaign, IL: Human Kinetics.

Schmolesky, Matthew T., David L. Webb, and Rodney A. Hansen. 2013. "The Effects of Aerobic Exercise Intensity and Duration on Levels of Brain-Derived Neurotrophic Factor in Healthy Men." *Journal of Sports Science and Medicine* 12 (3): 502–511.

Schulkin, J. 2000. "Theory of Mind and Mirroring Neurons." *Trends in Cognitive Sciences* 4 (7): 252–254. doi:10.1016/S1364-6613(00)01500-X.

Scibinetti, Patrizia, Nicoletta Tocci, and Caterina Pesce. 2011. "Motor Creativity and Creative Thinking in Children: The Diverging Role of Inhibition." *Creativity Research Journal* 23 (3): 262–272.

Shipstead, Zach, Thomas S. Redick, and Randall W. Engle. 2012. "Is Working Memory Training Effective?" *Psychological Bulletin* 138 (4): 628–654. doi:10.1037/a0027473.

Shors, Tracey J. 2014. "The Adult Brain Makes New Neurons, and Effortful Learning Keeps Them Alive." *Current Directions in Psychological Science* 23 (5): 311–318. doi:10.1177/0963721414540167.

Smallwood, Nicola, Meg J. Spriggs, Christopher S. Thompson, Carolyn C. Wu, Jeff P. Hamm, David Moreau, and Ian J. Kirk. 2015. "Influence of Physical Activity on Human Sensory Long-Term Potentiation." *Journal of the International Neuropsychological Society* 21 (10): 831–840. doi:10.1017/S1355617715001095.

Spencer, John P., Melissa Clearfield, Daniela Corbetta, Beverly Ulrich, Patricia Buchanan, and Gregor Schöner. 2006. “Moving Toward a Grand Theory of Development: In Memory of Esther Thelen.” *Child Development* 77 (6): 1521–1538. doi:10.1111/j.1467-8624.2006.00955.x.

Steggemann, Yvonne, Kai Engbert, and Matthias Weigelt. 2011. “Selective Effects of Motor Expertise in Mental Body Rotation Tasks: Comparing Object-Based and Perspective Transformations.” *Brain and Cognition* 76 (1): 97–105. doi:10.1016/j.bandc.2011.02.013.

Stummer, W., K. Weber, B. Tranmer, A. Baethmann, and O. Kempski. 1994. “Reduced Mortality and Brain Damage after Locomotor Activity in Gerbil Forebrain Ischemia.” *Stroke: A Journal of Cerebral Circulation* 25 (9): 1862–1869.

Theill, Nathan, Vera Schumacher, Rolf Adelsberger, Mike Martin, and Lutz Jäncke. 2013. “Effects of Simultaneously Performed Cognitive and Physical Training in Older Adults.” *BMC Neuroscience* 14 (September): 103. doi:10.1186/1471-2202-14-103.

Thelen, E. 1995. “Motor Development: A New Synthesis.” *American Psychologist* 50 (2): 79–95.

Thelen, Esther. 2004. “The Central Role of Action in Typical and Atypical Development.” In *Movement and Action in Learning and Development*, 49–73. Amsterdam: Elsevier.

Thompson, Todd W., Michael L. Waskom, Keri-Lee A. Garel, Carlos Cardenas-Iniguez, Gretchen O. Reynolds, Rebecca Winter, Patricia Chang, et al. 2013. “Failure of Working Memory Training to Enhance Cognition or Intelligence.” *PLoS ONE* 8 (5): e63614. doi:10.1371/journal.pone.0063614.

Tomporowski, Phillip D. 2009. “Methodological Issues: Research Approaches, Research Design, and Task Selection.” In *Exercise and Cognitive Function*, 91–113. Hoboken, NJ: John Wiley and Sons.

Tomporowski, Phillip D., Kate Lambourne, and Michelle S. Okumura. 2011. “Physical Activity Interventions and Children’s Mental Function: An Introduction and Overview.” *Preventive Medicine* 52 (Suppl 1, June): S3–S9. doi:10.1016/j.ypmed.2011.01.028.

Tomporowski, Phillip D., Bryan A. McCullick, and Michael A. Horvat. 2010. “Role of Contextual Interference and Mental Engagement on Learning.” In *Educational Games: Design, Learning, and Applications,* edited by F. Edvardsen and H. Kulle, 127–155. Hauppauge, NY: Nova Science.

Tomporowski, Phillip D., Bryan McCullick, Daniel M. Pendleton, and Caterina Pesce. 2015. “Exercise and Children’s Cognition: The Role of Exercise Characteristics and a Place for Metacognition.” *Journal of Sport and Health Science* 4 (1): 47–55. doi:10.1016/j.jshs.2014.09.003.

Tomporowski, Phillip, Bryan McCullick, and Catherine Pesce. 2015. *Enhancing Children’s Cognition with Physical Activity Games*. Champaign. IL: Human Kinetics.

Tomporowski, Phillip D., Jack A. Naglieri, and Kate Lambourne. 2012. “20 Exercise Psychology and Children’s Intelligence.” In *The Oxford Handbook of Exercise Psychology*, edited by Edmund O. Acevedo, 409. Oxford: Oxford University Press.

Tsai, Chia-Liang, Chun-Hao Wang, and Yu-Ting Tseng. 2012. “Effects of Exercise Intervention on Event-Related Potential and Task Performance Indices of Attention Networks in Children with Developmental Coordination Disorder." *Brain and Cognition* 79 (1): 12–22. doi:10.1016/j.bandc.2012.02.004.

Vaynman, Shoshanna S., Zhe Ying, Dali Yin, and Fernando Gomez-Pinilla. 2006. "Exercise Differentially Regulates Synaptic Proteins Associated to the Function of BDNF." *Brain Research* 1070 (1): 124–130. doi:10.1016/j.brainres.2005.11.062.

Waddell, Jaylyn, Megan L. Anderson, and Tracey J. Shors. 2011. "Changing the Rate and Hippocampal Dependence of Trace Eyeblink Conditioning: Slow Learning Enhances Survival of New Neurons." *Neurobiology of Learning and Memory* 95 (2): 159–165. doi:10.1016/j.nlm.2010.09.012.

Weinstein, Andrea M., Michelle W. Voss, Ruchika Shaurya Prakash, Laura Chaddock, Amanda Szabo, Siobhan M. White, Thomas R. Wojcicki, et al. 2012. "The Association between Aerobic Fitness and Executive Function Is Mediated by Prefrontal Cortex Volume." *Brain, Behavior, and Immunity* 26 (5): 811–819. doi:10.1016/j.bbi.2011.11.008.

Winter, Bernward, Caterina Breitenstein, Frank C. Mooren, Klaus Voelker, Manfred Fobker, Anja Lechtermann, Karsten Krueger, et al. 2007. "High Impact Running Improves Learning." *Neurobiology of Learning and Memory* 87 (4): 597–609. doi:10.1016/j.nlm.2006.11.003.

Wraga, Maryjane, William L. Thompson, Nathaniel M. Alpert, and Stephen M. Kosslyn. 2003. "Implicit Transfer of Motor Strategies in Mental Rotation." *Brain and Cognition* 52 (2): 135–143.

Wright, M. J., D. T. Bishop, R. C. Jackson, and B. Abernethy. 2011. "Cortical fMRI Activation to Opponents' Body Kinematics in Sport-Related Anticipation: Expert-Novice Differences with Normal and Point-Light Video." *Neuroscience Letters* 500 (3): 216–221. doi:10.1016/j.neulet.2011.06.045.

Xu, Jiansong, Vince D. Calhoun, and Marc N. Potenza. 2015. "The Absence of Task-Related Increases in BOLD Signal Does Not Equate to Absence of Task-Related Brain Activation." *Journal of Neuroscience Methods* 240 (January): 125–127. doi:10.1016/j.jneumeth.2014.11.002.

Young, Jeremy, Maaike Angevaren, Jennifer Rusted, and Naji Tabet. 2015. "Aerobic Exercise to Improve Cognitive Function in Older People without Known Cognitive Impairment." *Cochrane Database of Systematic Reviews* 4 (April): CD005381. doi:10.1002/14651858.CD005381.pub4.