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Run for Your Life! Childhood Physical Activity Effects on Brain and Cognition

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The past two decades have uncovered the beneficial relation of physical activity and other health behaviors on brain and cognition, with the majority of data emerging from older adult populations. More recently, a similar research thread has emerged in school-aged children, which offers insight into the relation of physical activity to scholastic performance, providing a real-world application of the benefits observed in the laboratory. Technological advances have similarly furthered our understanding of physical activity effects on cognitive and brain health. Given this emerging body of work, this manuscript reviews the basic findings within the field, but more importantly suggests triggers or signals from the emerging literature that will shape the field in the near future. The overall goal of this body of research is to increase cognitive and brain health to promote effective functioning of individuals across the lifespan.

Keywords: brain, cognition, fitness, lifespan, development, aging

In recent years, people have become more physically inactive. Across many facets of life (e.g., transportation, vocation, etc.), activities that once demanded substantial physical effort can now be accomplished with little physical demand. Vaynman and Gomez-Pinilla (2006) have suggested that human beings are victims of their own ingenuity, having engineered physical activity (PA) from their lives. We now know that an inactive lifestyle is detrimental to health, and leads to the increased prevalence of several chronic diseases (e.g., obesity, cardiovascular disease). Further, certain diseases, such as type-II diabetes, which were once considered to have an adult onset, are now growing in incidence and prevalence among children and adolescents (Dabelea et al., 2014). Such findings are alarming, as recent reports forecast that physical inactivity will continue to rise throughout the industrialized world over the next few decades (Ng & Popkin, 2012). Given these trends, there is a need to develop novel approaches to alter the course of inactivity and its consequent diseases.

Of related interest is the growing public health focus on the effect of physical inactivity on cognitive and brain health, which over the last two decades has received increased attention across several academic disciplines (Colcombe & Kramer, 2003; Donnelly et al., 2016). Across the lifespan, findings have demonstrated a positive influence of PA and aerobic fitness on cognitive and brain outcomes, and in children these findings have been extended to the academic setting where PA has been related to the classroom environment and the context of learning. Accordingly, the aim of this manuscript is to provide a brief history and context for the field of PA and aerobic fitness on cognitive and brain health across the lifespan. More importantly though, the purpose is to examine ‘triggers’ or ‘signals’ among the current state of the field that allow us to predict future directions that are ripe for growth in the near future (i.e., 5–10 years).

History

Our present understanding of the relationship between PA and cognitive function rests on critical contributions over the past 50 years. One of the pioneers was William P. Morgan, who observed a positive association between grip strength and recovery from depression in patients during the 1960s (Morgan, 1968; 1969) as well as the anxiety-reducing effects of aerobic exercise (Morgan, 1979; 1985); these foundational studies spawned the investigative efforts of today. Subsequent studies by Herbert deVries and colleagues (deVries, 1968; deVries & Adams, 1972) were among the first to employ objective psychophysiological measures, specifically electromyography (EMG), to assess the “tranquilizer” effect of PA and offered a plausible mechanism for the robust relaxation effect via reduced afference from skeletal muscle activity.

Spirduso (1983) observed the impact of PA on dopaminergic activity in rodents and the elevation of reactive capacity (i.e., shorter reaction times [RTs]), while Sherwood and Selder (1979) subsequently reported that men who were physically active (i.e., engaged in

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cardiovascular training) maintained the speed of their RT as age increased relative to sedentary men who showed age-related slowing. This remarkable finding suggested the reduction of brain aging through a physically active lifestyle. Later efforts to study exercise effects on brain chemistry (Dishman, 1997; Meeusen et al., 1997) were essentially built upon this early work.

The research on brain aging evolved with the first randomized clinical trial (RCT) of exercise on cognitive function in older men and women reported by Dustman et al. (1984), and was complemented in the early 1990s by a study in which direct assessment of brain activity was introduced with the use of electroencephalography (EEG) and event-related potentials (ERPs). Their findings revealed that high-fit older men exhibited relatively efficient neural activity similar to that of younger men (Dustman et al. (1990), providing a "fountain of youth" with compelling reports of angiogenesis in the brains of rodents (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990) and enhanced cerebral perfusion in older retirees who remained physically active (Rogers, Meyere, & Mortel, 1990). Importantly, Chodzko-Zajko and Moore (1994) were among the first to recognize specificity in the cognitive benefits of exercise, while Kramer et al. (1999) significantly advanced this concept, noting that executive function was particularly improved in older men and women through engagement in PA. Bolstered by the results of a meta-analysis provided by Colcombe and Kramer (2003), it was thought that exercise-induced specificity on executive function was likely due to accelerated decline of the frontal lobes with age (West, 1996) and greater opportunity for exercise-induced benefit relative to other brain regions. In addition, the neurogenic and neurotrophic effects of exercise observed in animal studies provided biological plausibility (Neeper et al., 1995; van Praag, Christie, Sejnowski, & Gage, 1999; van Praag, Kempermann, & Gage, 1999) for the impact of exercise on the brain and were summarized in compelling reviews (Cotman & Berchtold, 2002; Cotman, Engesser-Cesar, Bdnf, & Expression, 2002). The effects were pronounced in the hippocampus of the rodent brain, a region particularly vulnerable to the pathology associated with dementia such as Alzheimer's disease in humans, which revealed the benefit of PA to episodic memory function.

Colcombe et al. (2003) were the first to employ structural brain imaging (magnetic resonance imaging [MRI]), which revealed a positive relationship between cardiovascular fitness and gray matter tissue density as well as the integrity of white matter in older men and women, while further evidence of benefit was provided by Colcombe et al. (2004), who were the first to observe the beneficial effects of cardiovascular conditioning on cortical and subcortical activation during executive challenge through the employment of functional MRI (fMRI). As interest grew in the potential impact of exercise, Erickson et al. (2011) reported enhancement of hippocampal volume, a key brain region for memory formation, through exercise training in older men and women. This work holds profound implications for the prophylactic effect on normal brain aging and dementia and was accompanied by additional studies of brain connectivity, which appears more efficient in those who exercise (Burdette et al., 2010; Voss et al., 2010). Following the landmark work of Schuit and colleagues (2001), who reported cognitive benefits of PA in those at genetic risk for cognitive decline (i.e., carriers of the ApoE4 allele), Deeny et al. (2008) reported similar neural responses of physically active e4 carriers during a working memory challenge to those of noncarriers. A related study by Baker et al. (2010) revealed the cognitive benefit of PA engagement in adults diagnosed with mild cognitive impairment (MCI).

Studies of children have appeared more recently in the literature and they support superior executive control, better academic performance, and positive shifts in brain structure and function (Sibley & Etnier, 2003). Hillman, Castelli, and Buck (2005) were the first to assess brain function in children and reported that those who were high-fit exhibited greater cortical responsiveness when compared with low-fit children. Subsequently, Davis et al. (2011) examined the effect of exercise from a neurobiological perspective using fMRI and reported confirmatory evidence for the benefit of exercise on executive function in children.

As such, the history of research on exercise and the brain now extends across the lifespan and it may be that exercise-induced adaptations in the brains of children impact cognitive function in later life. Collectively, both prospective and retrospective epidemiological studies, as well as the experimental studies with animal and human subjects, strongly support the lifelong effects of a physically active lifestyle with promising results for brain development and aging. It is truly amazing to consider the remarkable advances in our understanding of the influence of PA on brain and cognition in a period spanning just 50 years from the seminal work of Morgan and Spirduso in the 60s and mid-70s to the present time with sophisticated molecular biology and advanced neuroimaging techniques. In essence, modern science is providing confirmatory evidence for the philosophy of the ancient Greeks who advocated *mens sana in corpore sano*, or a "healthy mind within a healthy body."

Current State of Research

To date, a significant understanding of the role of PA for cognitive and brain health has emerged using paper-and-pencil assessments of cognitive function, computerized batteries of cognitive processing, and neuroimaging tools illustrating alterations in brain morphology and function. To that end, this has been an exciting time for the field, with the number of publications examining the effects of childhood PA on cognition and brain growing exponentially each year. This section will briefly review the state of the research in children, but will rely upon research in adults for instances where evidence is currently lacking, which will serve to facilitate discussion in later sections with the purpose of focusing on the future of the field.

An understanding of the association between PA and brain morphology across the lifespan has occurred through measurement of the volume and integrity of various brain structures. In particular, aerobic fitness has been associated with subcortical structures such as the basal ganglia (Chaddock et al., 2010b; Verstynen et al., 2012) and hippocampus (Chaddock et al. 2010a; Erickson et al., 2009; 2010; 2011), such that higher levels of aerobic fitness are related to greater volume of these structures. Importantly, selective advantages for tasks that are mediated by these specific structures are also observed (Erickson et al., 2009). Additional evidence comes from the estimation of the integrity of white matter microstructure, which has found greater fractional anisotropy (i.e., greater integrity) along specific tracts in higher fit children and older adults relative to their lower fit counterparts (Krafft et al., 2014; Oberlin et al., 2016). Such findings are important because greater integrity of white matter has been related to better executive function (i.e., tasks requiring the intentional component of environmental control) in children and adults (Chaddock-Heyman et al., 2013; Oberlin et al., 2016). Recent estimates of cortical gray matter have further indicated that aerobic fitness is related to cortical thickness and arithmetic achievement during childhood (Chaddock-Heyman et al., 2015).

In later adulthood, most research in this area has focused on the associations between PA and fitness with gray matter volume and white matter microstructure to examine whether lifestyle behaviors are capable of modifying the course of brain atrophy (Erickson, Leckie, & Weinstein, 2014). This literature has largely supported the conclusion that both the volume of the prefrontal cortex and hippocampus are associated with PA and fitness. Yet, whether these effects translate to a modification in the risk for dementia or a significantly altered change in cognitive performance remains a matter of speculation.

In children, considerably more attention has been paid to the assessment of fitness and brain function. Accompanying a wealth of correlational evidence that has compared children across specific fitness groupings or the entire fitness spectrum, recent randomized controlled trials have demonstrated a beneficial effect of afterschool PA interventions on brain function using techniques that image the neuroelectric (Hillman et al., 2014; Kamijo et al., 2011) and hemodynamic (Chaddock-Heyman et al., 2013; Davis et al., 2011) systems. Despite the fact that consensus has not occurred regarding the specific regions or directionality of change in brain activation as a function of PA, all studies have indicated benefits to cognition. In addition, some evidence suggests that incremental gains in PA may be related to the magnitude of change in brain function, cognition, or academic performance (Davis et al., 2011; Hillman et al., 2014).

To that end, the relation of PA to brain structure and function are more valuable to public health and education when accompanied by changes in behavior (i.e., cognition). Although several aspects of cognition have demonstrated benefits associated with PA or aerobic fitness, the greatest evidence has emerged from studies examining executive control (Donnelly et al., 2016) and, more recently, hippocampal-dependent memory (Chaddock et al., 2010a; Erickson et al., 2011). Executive control refers to a subset of cognitive operations including inhibition, working memory, and cognitive flexibility. Relevant to the study of children, executive control is thought to underlie, in part, select aspects of scholastic performance. Further, certain aspects of memory, known as relational or associative memory, rely upon the functional integrity of the hippocampus. Multiple studies have observed greater hippocampal-dependent memory in higher-, compared with lower-fit, children (Chaddock et al., 2010a) and adults (Erickson et al., 2011). Given that the hippocampus is integral to memory and learning, PA may, in part, underlie improvements in scholastic performance via the integrity of this structure and improve memory performance in older adults that are at risk for memory decline.

Accordingly, childhood PA has been linked to cognitive and brain health, and has implications for scholastic performance. Such findings have been demonstrated using RCTs lasting several months, as well as via single, brief bouts of exercise (Hillman et al., 2009; Pontifex et al., 2012). Although the benefits of a single bout of PA are brief, they demonstrate a ‘quick fix’ approach to enhancing cognitive and scholastic performance, and may provide insight into the mechanisms underlying changes in brain and cognition following sustained involvement in PA. Despite these interesting findings, many unanswered questions remain regarding how PA enhances brain and cognition, including what conditions and constraints are necessary for PA to maximize brain and cognition across the lifespan. Though considerable, ongoing research in the laboratory and in real-world settings such as schools are underway; several interesting ‘triggers’ or ‘signals’ have emerged, allowing for the projection of future trends and research directions that will ultimately provide the necessary information to use PA as a tool to enhance cognitive and brain health across the lifespan.

Triggers/Signals

Physical Activity, Fitness, and Sedentary Behavior

One of the challenges in studies of the relation of health behaviors to brain and cognition is teasing apart the independent contributions of each behavior to the outcomes of interest. This is especially challenging here because PA, fitness, and sedentary behavior are closely linked constructs that influence one another. However, recent evidence has emerged to suggest that some differences between these constructs might exist when focused on cognitive and brain health. Recent reports suggest conflicting results regarding the relation of PA and aerobic fitness to cognitive and academic outcomes, with some researchers finding benefits of PA (Syväoja et al., 2013; Syväoja et al., 2014) and others finding benefits of fitness, but not PA (Pindus et al., 2016). Further, distinctions between objectively-measured (e.g., accelerometry) and subjectively-measured PA (i.e., self-report) have led to further confusion regarding the role of these health factors on cognitive and academic performance (Syväoja et al., 2013; Syväoja et al., 2014).

At the heart of these conflicting findings is the difficulty of accurately measuring PA, especially among children. That is, objective measures are either reliable, yet expensive and cumbersome, or, in the case of subjective measures, inexpensive and easy to assess, but subject to biases (Brener et al., 2003). Lastly, few studies, have assessed the relation of sedentary behavior on cognitive and brain outcomes in a systematic manner (see Syväoja et al., 2014 for an exception). Accordingly, understanding the unique role of various health factors (e.g., PA, fitness, sedentary) on cognitive and brain outcomes is a trigger that will develop over the next 5–10 years. Evidence for this prediction stems from the fact that few scientists were asking questions concerning these distinctions 5 years ago; yet, today, multiple manuscripts may be found in an effort to provide a more comprehensive overview of the relation of PA and fitness to brain and cognition. The inclusion of sedentary time is a recent addition to the literature, and as measurement devices continue to develop, this health behavior will be assessed with more rigor.

Synergy with Other Health Factors

Related to the focus of the prior section, other health factors have been found to contribute to cognitive and brain health. That is, excess adiposity has been linked to lower brain morphology (Raji et al., 2010; Verstynen et al., 2012), brain function (Kamijo et al., 2012a; Kamijo et al., 2014b; Tregellas et al., 2011), executive control (Schwartz et al., 2013), and academic performance (Caird et al., 2014; Smith et al., 2011). Similarly, symptoms of metabolic syndrome have also evidenced a relationship with brain structure (e.g., hippocampal volume, reduced white matter integrity), cognition (i.e., inhibition, mental flexibility), and academic (e.g., mathematics) outcomes (Scudder et al., 2015; Yau et al., 2012). Accordingly, other health outcomes (e.g., diet quality, hydration) likely play a role in cognitive and brain health, but also may synergistically enhance important outcomes (e.g., PA and hydration) or compete against one another (e.g., PA and a diet rich in simple sugars and saturated fats).

Some relevant examples exist, suggesting that the larger study of health outcomes and their synergy/discord with PA may be a valuable signal for future research. That is, the relationship of PA to brain and cognition has suggested that afterschool PA programming is an important tool to improve health outcomes in children with excess adiposity (Davis et al., 2011). Similarly, PA may interact with a diet high in omega-3 fatty acids to influence executive function in midlife adults (Leckie et al., 2014). However, the vast majority of research only considers a single category of health outcomes (e.g., PA/fitness, diet/nutrition, or excess adiposity). Despite this limitation, research in all areas have been increasing in recent years, and with the formation of multidisciplinary teams, a more comprehensive understanding of health outcomes to brain and cognition is a likely signal for future research efforts.

Linking the Research Laboratory with the Classroom

The illustration of PA (and other health factors) to cognition and brain in a laboratory setting is interesting to scientists, but becomes much more powerful for the general public when depicted in everyday life. This field has grown dramatically in the last 10 years due to an established link between PA and cognition, not only in the laboratory, but also in the classroom (see Donnelly et al., 2016 for review). Recent evidence has emerged to indicate that PA is related to outcomes important for academic success, including standardized achievement testing (Castelli et al., 2007; Donnelly et al., 2009), class grades (Syväoja et al., 2013), and classroom behavior (Mahar et al., 2006). More recently, similar relationships have emerged for motor skill performance and academic outcomes (Ericsson & Karlsson, 2014; Haapala et al., 2014; Jaakkola et al., 2015). Early research has also linked academic performance with differential function of the neuroelectric system (Moore et al., 2014; Scudder et al., 2014). That is, reading comprehension (Scudder et al., 2014) and arithmetic verification (Moore et al., 2014) tasks have been used to assess the N400 component, embedded within the neuroelectric signal during information processing operations. In both studies, higher fit preadolescent children (9–10 years) demonstrated larger magnitude of the N400, indicating more effective functioning of this system in the service of task performance. Further, higher fit children outperformed their lower fit peers on a standardized achievement test, suggesting that the N400 might be a viable biomarker of scholastic performance. However, both studies are correlational in nature and will need to be followed by RCTs to determine causality, providing a signal for the future direction of the field.

To date, the vast majority of research on PA and scholastic outcomes has studied academic *performance*. In other words, although *learning*, which is truly the outcome of interest, is assumed from such studies, it has not been directly assessed, with one noted exception (Raine et al., 2013). Raine and colleagues had higher and lower fit 9–10-year-olds visit the laboratory on two occasions, wherein they learned the names of regions of fictitious maps on the first day, and had to recall the novel information they had learned on the second day, which occurred 24 hr later. The findings revealed that both groups encoded the novel information equally on day one. However, 24 hr later, higher fit children had learned the novel material better relative to lower fit children, especially during more difficult conditions. Thus, the demonstration of better learning and memory in higher fit children is an obvious signal for future research, as multiple questions surrounding the mechanistic nature and causality are sorely needed. Further, understanding the acute (Hillman et al., 2009; Pontifex et al., 2012) and chronic (Davis et al., 2011; Donnelly et al., 2009; Hillman et al., 2014) PA conditions (i.e., temporality, dose, etc.) under which the greatest gains in learning and performance may occur are secondary questions that are clear signals for future research. Such a future direction will provide much-needed information on factors that influence children's academic success.

Physical Activity and Cognition Across the Lifespan

The field of PA and cognition has progressed in a manner such that most of the focus has been paid to older adults between the ages of 60–75 years, followed by research in school-aged children, particularly preadolescent children of secondary school age. Although a scattering of studies have focused on young adults, relatively little is known regarding the remainder of the lifespan, including middle age (see Åberg et al., 2009 for a notable exception), adults over 80 years of age, and preschool age children (< 6 years).

Even though considerable interest in studying PA in children of preschool age exists, several barriers must be overcome. Most importantly, the United States has not established guidelines for PA in children under the age of 6 years. Further, objective and subjective measurement of PA can be challenging for a number of reasons (e.g., validity of guardian's self-report of child's PA behavior, suitability of wearable technology for young children). Despite these barriers, validation of wearable technology in preschool age children (Adolph et al., 2012) and reviews of factors that influence preschool children's PA behavior have been reported (Hinkley, Crawford, Salmon, Okely, & Hesketh, 2008). Regardless, considerably more work on PA behaviors of preschool age children is necessary, making this a signal for future research.

In addition to overcoming barriers to assessing PA in preschool age children, there are barriers to assessing cognition and brain in this age group. Given that the brain is rapidly maturing throughout the course of development, cognitive functions mediated by the various brain structures and networks is also maturing. Specific regions such as the prefrontal cortex, which are part of the network that underlies executive functions, demonstrates protracted development and thus these functions do not mature until later in development (Diamond, 2006). Accordingly, variability in cognitive performance would be expected, especially under situations where a relationship with health outcomes is considered. As such, although the study of PA to cognition and brain in children under 6 years of age is a signal for future research, it is clear that this area will have to proceed cautiously due to multiple barriers.

Similar to young children, studying the effects of PA on brain and cognition in adults over the age of 80 also faces a number of challenges. Many adults in this age range have limited mobility, arthritis, cardiometabolic conditions, or are experiencing cognitive decline or impairment that limit their safe engagement in PA. These issues influence participation and eligibility into research studies, which in turn, limits our ability to determine the degree to which this age range benefits from activity. Nonetheless, given the health conditions of many individuals in this age range, increasing and encouraging some form of PA may help mitigate cognitive decline and brain atrophy while also positively influencing other health conditions.

The Future of Neuroimaging

As described above, the development of *in vivo* neuroimaging methods have significantly added to our understanding of the ways in which PA and fitness influence brain and behavior. These methods include neuroelectric indices as well as MRI and positron emission tomography (PET) approaches. Each method has its strengths and limitations, but MRI has gained considerable traction because it is relatively noninvasive and highly versatile. Several different parameters and outcomes can be derived from data collected through MRI, including cortical thickness, gray matter volume, integrity of white matter microstructure, cerebral blood flow, white matter lesions, functional connectivity, task-evoked brain activation, concentration of brain metabolites, myelin content, and many others. Although the majority of studies using MRI have assessed brain morphology with an adult sample (Erickson et al., 2014), the amazing versatility of MRI has triggered the field to use it in other ways to provide a more complete understanding of the associations between PA and brain health.

Results from neuroimaging studies have triggered the development of sophisticated MRI sequences that target subfields of the hippocampus. As described above, it appears that PA and fitness are associated with hippocampal volume and integrity, yet we still do not know whether the effects are localized to particular subfields (e.g., dentate gyrus). Such imaging specificity may shed light on the cellular and molecular mechanisms underlying these volumetric changes and clarify which memory processes might be most linked to these changes. Further, the acquisition of high-resolution anatomical data has allowed investigators to examine changes in cortical thickness (Chaddock-Heyman et al., 2015; Herting, Keenan, & Nagel, 2016) and to use these outcomes to determine if they mediate the effects of PA on certain behaviors (e.g., relational memory). Such computational and statistical advances are important as they provide more sophisticated ways to manage the massive amounts of data collected in MRI paradigms and provide means for discovering new outcomes that may have clinical or public health applications.

In addition to a focus on changes in gray matter volume, there have been major strides in the development of tools and MRI sequences to target white matter microstructure and myelin content. As such, these methodological and computational developments will trigger studies to examine how PA influences specific white matter tracts and how these changes mediate improvements in behavior. For example, Oberlin et al. (2016) employed a statistical mediation analysis on a point-by-point basis throughout the white matter skeleton. They found that greater white matter integrity in several different white matter tracts statistically mediated improvements in spatial memory performance. Such analyses throughout the skeleton would not have been possible 5 years ago, but the evolution of software and computational power has provided the field with a way to test important hypotheses about the relation of brain and PA. This trend will continue over the next 5–10 years.

In addition to the above advancements, the development of graph theory approaches for the analysis of resting state functional connectivity data, the generation of machine learning and classification algorithms, and the continued development of MRI sequences (Erickson, Miller, & Roecklein, 2012) will allow questions about the regional specificity and connectivity effects of PA to be examined. These approaches will allow researchers to examine the brain as networks of regions and assess whether the communication between regions changes as a function of PA. The combination of approaches in a multimodal analysis framework will shed additional light on how PA and fitness influence brain health and function across the lifespan and its impact on disease and scholastic achievement.

Biomarkers of Physical Activity on Brain and Cognition

Some of the molecular and cellular pathways for the effects of PA on the brain have been identified from animal studies. Human studies, however, are inherently limited in this regard. However, numerous studies are now taking blood from human subjects to examine whether certain molecular pathways that have some basis or origin in peripheral tissues could act as biomarkers for the brain benefits of PA, or be assessed as potential mechanistic pathways by which PA exerts its effects on the brain. There are numerous candidate blood-based markers that are currently being examined including insulin pathways (Maass et al., 2016), inflammatory cytokines (Jackson et al., 2016), brain-derived neurotrophic factor (Erickson et al., 2011), and cathepsin B (Moon et al., 2016), among others (Prakash et al., 2015). It is likely that in the next 5–10 years we will have a better and more complete understanding of the importance of these biomarkers in the context of PA and brain health.

The use of biomarkers in the context of studies examining PA and brain outcomes also includes the evolution of new techniques and approaches, such as multiplex assays, that can gather information on a wide-array of molecules at once. This will allow the discovery of as-of-yet unidentified molecular pathways involved in both PA and brain health. Another approach includes an examination of DNA methylation, which may change over the time-span of a PA intervention and correlate with cognitive and brain changes. Such advancements will foster translation of basic science to public health outcomes and identify molecular mechanisms that form the basis for the cognitive and brain changes elicited by PA.

Conclusion

The scientific study of PA to brain and cognition has clearly gained traction over the past 50 years due to advances in technology and a larger focus on lifespan health and function. Despite these advances, there is still much that remains unknown. The aim of this article was to project the direction, and advances in the field, in the near future, i.e., the next 5–10 years. Based on signals from intriguing early investigations, we predicted future advances in the field of PA, brain, and cognition in: the study and synergy of related health factors (e.g., sedentary behavior), movement out of the laboratory and into everyday life, greater focus on lifespan health including preschool aged children and adults over 80 years, and the continued innovation of neuroimaging tools and identification of biomarkers. The ultimate goal of this area of research is to increase cognitive and brain health and improve effective functioning of all individuals during childhood and across the lifespan. The signals identified herein should provide some of the necessary means to advance the field and make progress toward achieving this goal over the next decade.

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