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Testing the association between physical activity and executive function skills in early childhood

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ABSTRACT

This study examined the cross-sectional association between multiple aspects of objectively measured physical activity (sedentary, light, moderate to vigorous) and children's executive function skills. Participants included 85 children, ages 3–5, who were recruited from 10 center-based preschools. On the basis of up to 5 weekdays of accelerometer data, children spent an average of 57.5% of their time in a sedentary state, 30.7% in light physical activity, and 11.8% in moderate to vigorous physical activity. Whereas individual differences in sedentary behavior and light physical activity were unrelated to executive function, contrary to study hypotheses, moderate to vigorous physical activity was inversely related to performance on executive function tasks ($\beta = -.28$, 95% CI = −.50 to −.06). Results are discussed with respect to the importance of extending evidence that links increased physical activity to executive function skills, which are based on studies involving older children and adults, to the early childhood period, as well as the design and measurement issues that should inform this work.

1. Introduction

Executive function (EF) skills are an array of cognitive processes that are drawn upon to support problem solving efforts and that support self-regulation (Blair & Ursache, 2011; Hofmann, Schmeichel, & Baddeley, 2012). Although numerous cognitive processes have been described as EF (Barkley, 2012), inhibitory control, working memory, and cognitive flexibility are the three core domains of EF that are most often studied in early childhood (Garon, Bryson, & Smith, 2008). There is widespread interest in EF skills both because they contribute to interpersonal, academic, educational, and occupational success and because they are malleable though interventions (Diamond, 2012; Hsu, Novick, & Jaeggi, 2014; Zelazo, Blair, & Willoughby, 2016).

Individual differences in physical activity (PA), especially moderate to vigorous physical activity (MVPA), are associated with enhanced neurocognitive and brain functioning in adults (Kirk-Sanchez & McGough, 2014; Kramer et al., 2003). The benefits of increased PA are particularly salient for EF skills relative to other aspects of cognitive functioning (Colcombe & Kramer, 2003). The benefits of PA on EF skills result from the direct impact of increased PA on improved neural structure and function (van Praag, 2009; Voss, Vivar, Kramer, & van Praag, 2013; Weinstein et al., 2012). Although the specific processes that link PA to changes in neural structure and function are not fully elucidated, activity-induced changes in neurotrophic factors (Dishman et al., 2006; Leckie et al., 2014; Piepmeier & Etnier, 2015), neurotransmitters (Dishman et al., 2006), and possibly increased cerebral blood flow with corresponding angiogenesis (Guiney, Lucas, Cotter, & Machado, 2015; Machado, Guiney, Lucas, & Cotter, 2013; van Praag, 2009) have been implicated.

Although comparatively more research relating PA to EF skills has come from studies involving adults, a growing literature has extended this to school-aged child samples. In a meta-analysis of 44 studies involving school-aged children, Sibley and Etnier (2003) reported significant effects for both the acute ($d = .37$) and chronic ($d = .29$) effects of physical activity on children's cognitive and academic outcomes. More recent narrative reviews have also concluded that increased PA is associated with beneficial cognitive and academic outcomes in school-aged children (Donnelly et al., 2016; Poitras et al., 2016). Although much of this research is based on cross-sectional and passive longitudinal studies, multiple recent randomized controlled trials provide stronger evidence that increased PA may be causally related to improved brain structure and function as well as EF skills in school-aged children (Hillman, Khan, & Kao, 2015).

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Although early childhood is often characterized as a developmental period in which children are naturally active, this is a misperception. In a review of 30 studies that used objective methods for measuring PA in preschool settings, the median percentages of time that children spent in sedentary behavior, light PA, and MVPA were 77%, 17%, and 6%, respectively (Hnatiuk, Salmon, Hinkley, Okely, & Trost, 2014). Independent advisory commissions from the United States, the United Kingdom, Australia, and Canada have recommended that 3–5-year-old children should obtain at least 15 min of PA per hour which accumulates to approximately 3 h of PA per day, at least 1 h of which is ideally MVPA or "energetic play" (Department of Health and Ageing, 2010; IOM, 2011; Okely et al., 2017; Tremblay et al., 2016). A recent study in the United States, which involved two independent samples, reported that only 50% of preschool children meet the criterion of at least 15 min of PA per hour (Pate et al., 2015). A similar study in Australia reported that approximately 20% of children met this same criterion (Ellis et al., 2017). These findings are consistent with the results of a systematic review, which was published in this journal that concluded that only about 50% of preschool-aged children exhibited 1 h of MVPA per day (Tucker, 2008). The consistently low rates of PA that are observed among preschool-aged children in many Western countries has spurred multiple efforts to develop intervention approaches that increase PA in early childhood settings (Gordon, Tucker, Burke, & Carron, 2013; Ward, Vaughn, McWilliams, & Hales, 2010). The hope is that efforts to increase PA in preschoolers will contribute to multiple health outcomes including adiposity, bone and skeletal health, motor skill development, and cardiometabolic indicators (Carson et al., 2017).

Given the ongoing efforts to improve PA in early childhood and the potentially positive impacts PA may have on the development of EF skills (per studies involving school-aged children and adults), it is remarkable how few studies have tested whether PA is associated with EF skills in preschool-aged children. A recent systematic review of the effects of PA on general cognitive development in preschool-aged children only identified seven studies that involved 414 children (Carson et al., 2015). Carson et al. (2015) concluded that in the five studies that included EF outcomes, increased frequencies and/or longer durations of PA had beneficial effects on EF skills in 67% of the comparisons that were made with no instances of detrimental effects. However, collectively, the studies relating PA to EF skills were hampered by small sample sizes and generally considered to be of poor quality (Carson et al., 2015). We would additionally note that three of the five studies tested the impact of acute changes in PA on EF skills (Becker, McClelland, Loprinzi, & Trost, 2014; Mierau et al., 2014; Palmer, Miller, & Robinson, 2013), while a fourth study measured PA across 1 day of activity monitoring (Campbell, Eaton, & McKeen, 2002). None of these studies informed basic questions about whether stable individual differences in PA that are evident in early childhood are related to children's EF skills.

When we adopted a more inclusive definition of early childhood to include children who are enrolled in kindergarten, three additional studies that investigated the effects of PA on EF skills were identified (Chang, Tsai, Chen, & Hung, 2013; Fisher et al., 2011; Stein, Auerswald, & Ebersbach, 2017). In an experimental study involving 64 kindergarteners (M = 6.2 years old), Fisher et al. (2011) tested whether a modified physical education program (2 h/week across 10 weeks) was associated with improvements in EF relative to standard physical education. Although statistically significant differences were evident for a subset of EF tasks (spatial span, spatial working memory, attention network task), the authors suggested that their modified physical education program did not achieve the necessary increases in moderate to vigorous activity levels to obtain the expected effects. In an experimental study involving 26 kindergarteners (M = 7.1 years old), Chang et al. (2013) tested whether participation in a low- versus high-impact soccer training program (two, 35-min sessions/week for 8 weeks) resulted in improvements in EF. Children in both groups demonstrated pre–post improvements in performance on a flanker task, a widely used measure of inhibitory control—though the lack of a control group limited the interpretation of these results. In a third study of 101 kindergarteners (M = 6.0, range = 5–7.1 years old), Stein et al. (2017) tested the impact of a single bout (i.e., a 20-min session) of coordinated exercise on children's performance on EF tasks. Children who were randomized to the intervention condition did not exhibit improved performance on EF tasks relative to children in the comparison condition.

In summary, little is known about the association between PA and EF skills in preschool- or kindergarten-aged children. A few studies have tested how acute changes in PA are related to short-term changes in attention or EF skills, while others have involved relatively modest manipulations of PA over a period of multiple weeks. We are not aware of any study that has investigated whether stable individual differences in naturally occurring variation in PA among preschoolers are associated with EF skills. Given the evidence that links greater PA to more advanced EF skills in school-aged children, adolescents, and adults, we tested whether these associations were evident in early childhood. Moreover, in contrast to the preponderance of studies of children at all ages that have focused on short-term (i.e., acute) changes in PA as they relate to EF (see e.g., Verburgh, Konigs, Scherder, & Oosterlaan, 2014), we sought to investigate stable individual differences in PA that are best characterized with multiday observations of PA using accelerometry methods.

On the basis of studies that have involved older participants, we hypothesized that children with the highest levels of observed MVPA would perform best on EF tasks. Moreover, given some evidence that PA may preferentially affect inhibitory control in adults (see e.g., Barenberg, Berse, & Dutke, 2011), we also tested whether PA would be more strongly associated with inhibitory control than working memory aspects of EF in preschool-aged children.

2. Methods

2.1. Participants and procedures

A cross-sectional study was conducted to investigate the association between objectively measured PA and children's performance on direct assessments of EF skills. All study procedures were reviewed and approved by the RTI International Internal Review Board. To increase the likelihood of individual differences in PA, children were recruited from preschools that were members of a public-private consortium that seeks to increase PA and wellness of children in preschool settings. The directors from 16 preschools in central North Carolina were contacted to participate in the study; 10 directors agreed to participate. Center staff distributed a description of the study, consent forms, and a short demographic survey to the caregivers of all children in classrooms that served 3–5-year-olds. Consent forms and surveys were returned to the study office by mail or via the preschool teacher.

Caregivers were requested to have their children wear activity belts (accelerometers) for a 5-day period (Monday–Friday) during all waking hours. Written consent to participate was received from 106 children (2–16 children per preschool). In total, 21 children were excluded from analyses due to either the inability to complete any of the EF tasks (N = 3), insufficient measurement of PA recording (N = 17), or failure to return activity belts (N = 1), which resulted in a final sample of 85 children. Descriptive information on participating children is summarized in Table 1. Children in the final sample were on average 4.4 years old (SD = 0.7), 44% female,