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The effects of qualitatively different acute physical activity interventions in real-world settings on executive functions in preadolescent children☆

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ABSTRACT

There is growing evidence indicating a positive effect of acute physical activity on cognitive performance in children. Most of the evidence originates, however, from studies in highly controlled laboratory settings. The aim of the present study was to investigate whether the same effects can be found in more real-world settings. We examined the effects of qualitatively different acute physical activity interventions on the three core dimensions of executive functions (updating, inhibition, shifting). In an experimental between-subject design, 219 ten to twelve year-olds were assigned to one of four conditions which varied systematically in physical activation and cognitive engagement. Executive functions were measured before and immediately after the intervention. Contrary to the hypothesis, no effects of acute physical activity with and without cognitive engagement were found on executive functions in the overall sample. Only children with higher fitness and/or higher academic achievement benefitted from the interventions in terms of their updating performance. Thus, the results indicate that it may be more difficult to attain positive effects through acute physical activity in real-world settings than in laboratory settings and that physiological and cognitive requirements may have to be adjusted to individual capacity to make an intervention effective.

In the context of the increasing sedentary lifestyle, it is not surprising that the interest in the relation between physical activity (PA) and physical and cognitive health increased in recent years. In fact, there is evidence indicating not only positive relations between PA and physical development and health (Bailey, 2006), but between PA and cognitive performance (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014). Beyond this relationship, intervention studies indicate that PA can affect cognitive performance positively throughout the lifespan (Barenberg, Berse, & Dutke, 2011; Best, 2010; Chang, Labban, Gapin, & Etnier, 2012; Hillman, Erickson, & Kramer, 2008). Most studies in the area of acute PA, i.e., studies investigating the immediate effect of a single bout of PA, were conducted in laboratory settings and the PA interventions were mostly comprised of treadmill walking or ergometer cycling. This experimental design allows to control for a lot of confounding variables and to draw conclusions about the dose-response relationship. However, it is often difficult to translate the assessed programmes into praxis (Wójcicki & McAuley, 2014), especially in children's populations. Thus, it remains to be examined whether acute PA in more real-world settings, e.g., physical games in group settings, can affect cognitive performance in children in a similar way as treadmill walking or ergometer cycling in an individual and highly controlled laboratory setting seems to do.

The most promising aspect of cognitive functioning to be positively affected by PA seems to be the domain of executive functions (EF; Tomporowski, Lambourne, & Okumura, 2011). EF refer to the individual's ability to initiate, adapt, regulate, monitor, and control information processes and behavior (Diamond, 2013; Hughes & Graham, 2002; Miyake et al., 2000). In the literature, a division of

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EF into three core dimensions is suggested (Diamond, 2013; Miyake et al., 2000): updating (keeping relevant information in working memory and processing this information further), inhibition (ability to avoid dominant, automatic, or prepotent responses or resisting distractor interference as well as suppressing environmental interference), and shifting (moving back and forth between multiple tasks, operations, rules, or mental sets).

Studies investigating the effects of acute PA on EF in children show relatively consistent positive effects on inhibition (e.g. Best, 2012; Chen, Yan, Yin, Pan, & Chang, 2014; Drollette, Shishido, Pontifex, & Hillman, 2012; Hillman et al., 2009; Jäger, Schmidt, Conzelmann, & Roebers, 2014; Kubesch et al., 2009; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Studies assessing updating and shifting in children are more limited and several researcher failed to find effects in these dimensions (Budde et al., 2010; Coles & Tomporowski, 2008; Drollette et al., 2012; Jäger et al., 2014; Kubesch et al., 2009; Soga, Shishido, & Nagatomi, 2015; Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008). A recent study, however, showed positive effects on all three core dimensions of EF (Chen et al., 2014), indicating that, similar to adults, all three dimensions of EF can be affected through acute PA, with inhibition probably benefitting most easily (Barenberg et al., 2011).

According to these results, the positive effect of acute PA on EF in children seems to be relatively certain. However, as mentioned before, most results in this area originate from studies conducted in highly controlled laboratory settings and the translation of the assessed programmes into praxis is difficult. Especially in children's populations, two main questions arise with regard to this issue. First, it has to be examined whether acute PA interventions in more natural settings, e.g., in group settings, yield the same effects as interventions in individual and highly controlled laboratory settings. Second, it is unclear if PA interventions different from aerobic exercise, e.g., physical games, benefit EF performance similarly and which qualitative aspects of PA yields the strongest effect.

Starting with question one, only very few studies assessed the effects of acute PA on EF in natural settings. One study found improved performance in inhibition in 13- to 14-year-olds (Kubesch et al., 2009) and another study found improved performance in all three core dimensions of EF in 9-year-olds (Chen et al., 2014) after an acute bout of endurance-oriented exercise in a group setting similar to physical education. These results indicate that not only interventions in highly controlled laboratory settings, but also interventions in real-world settings seem to be effective in improving EF in children. Further studies are required to confirm this conclusion and, since both studies conducted endurance-oriented interventions, it remains to be examined if PA interventions different from aerobic exercise yield the same effects.

This leads us to the second question concerning qualitative aspects of PA interventions. Especially in children's populations, the question whether interventions different from aerobic exercise benefit EF equally is important, because solely endurance-oriented exercise does not accomplish the whole range of requirements of modern physical education (National Association for Sport and Physical Education, 2004). Physical games include higher motor-coordinative skills and/or enhanced executive control requirements, such as keeping in mind and updating rules, inhibiting movements, shifting flexibly between different situations, planning and acting anticipatory. Therefore, there is increasing interest in the effects of cognitive engagement during PA interventions on cognitive performance.

One study assessing the effects of physical games including cognitive engagement in 6- to 8-year-olds showed a stronger improvement in inhibition compared to a resting control group (Jäger et al., 2014). The design of this study did, however, not allow answering the question whether the physical activation, the cognitive engagement or the combination of these aspects accounted for the positive effects. This issue was treated in four other studies with children and adolescents. Two studies showed stronger cognitive improvements after a PA intervention with cognitive engagement than after an intervention without cognitive engagement (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Pesce Crova, Ceratti, Casella, & Bellucci, 2009). In another study (Best, 2012), no differences between effects of acute PA with and without cognitive engagement, and in a fourth study (Gallota et al., 2012) even detrimental effects of a combination of physical and cognitive engagement compared to solely physical or solely cognitive engagement were found. Given the inconsistent evidence regarding the question about which type of acute intervention in real-world settings may yield the strongest positive effect on cognitive performance, more studies comparing interventions with and without cognitive engagement are necessary.

Another question that arises when interventions are transferred into praxis is whether all children benefit equally from an intervention or if certain individual characteristics moderate the effects of PA on cognitive performance. Among others, physiological and cognitive factors may moderate the effects of PA on cognitive performance. Regarding physiological moderators, aerobic fitness is a prominent factor discussed in the literature. A meta-analysis (Chang et al., 2012) and two recent experimental studies (Chang et al., 2014; Hogan et al., 2013) indicate that subjects with higher fitness seem to benefit more from acute exercise in terms of cognitive performance. These studies included adult and adolescent samples. Therefore, it remains to be examined whether fitness has the same moderating effect in children. If so, this would need to be considered when an intervention is implemented and investigations about adaptations to attain a better outcome in children with lower fitness would be required.

Regarding cognitive performance as a moderating variable, it seems that children with the poorest baseline performance benefit most from short- and long-term interventions aimed at improving EF (Diamond, 2012; Drollette et al., 2014; Sibley & Beilock, 2007), possibly because they have more room for improvement (Tomporowski et al., 2008). This outcome conforms to the desired consequence of interventions because they usually aim at supporting individuals with poor performance. In the school context, it is particularly interesting if children with lower academic achievement benefit more from acute PA in terms of their EF performance because EF performance is not only strongly related to (Best, Miller, & Naglieri, 2011) but also predictive for academic achievement (Roebers et al., 2014). Thus, if EF performance would benefit from acute PA in children with lower academic achievement, acute PA might be a method to support these children.

Taken together, the current state of research indicates that acute PA affects EF in children positively. Several questions in this field of research are, however, still unclear, especially when it comes to practical relevance of previous findings. The aims of the present study were (1) to examine whether effects found in highly controlled laboratory settings can also be found in more natural settings, (2) to investigate what type of acute intervention, varying in the degree of physical and cognitive activation, yield the strongest effect on the three core dimensions of EF, and (3) to examine the moderating influence of aerobic fitness and academic achievement on the effects of acute PA interventions on EF in preadolescent children.

We expected a stronger improvement in children attending a PA intervention compared to the sedentary control conditions. The investigation of the qualitative aspects of the intervention had an exploratory character, because previous findings targeting this