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Searching for cognitively optimal challenge point in physical activity for children with typical and atypical motor development☆

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ABSTRACT

Statement of problem: Growing evidence testifies that different types of physical activity (PA) interventions promote cognitive development, but the specific impact of the cognitive demands inherent in PA still remains underconsidered. This study investigated whether (1) increasing the cognitive demands of PA positively impacts children's executive function and (2) this 'enrichment' also matches the ability/skill level of children with Developmental Coordination Disorder (DCD).
Methods: Two hundred and fifty children aged 5–10 years participated in different physical education interventions, lasting six months, with or without special focus on cognitively demanding PA. Before and after the intervention, children's executive function was tested with the attention and planning subscales of the Cognitive Assessment System and their motor developmental level classified as typical, borderline, or DCD according to their performance evaluated by the Movement Assessment Battery for Children.
Results: Among indices of executive function, those of Attention showed a differential effect of PA type as a function of children's motor developmental level: typically developing children gained greatest attentional benefit from PA with additional cognitive demands, while children with coordinative problems/impairment from the PA program without cognitive enrichment. Changes from DCD to borderline or normal developmental status did not differ in frequency as a function of intervention type.
Conclusions: Results showed that cognitively more or less challenging PA programs are differently efficacious for promoting attention development and highlight the need to find and continuously reset the degree of task complexity in PA to match the optimal challenge point of normal and special children populations.

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Strong evidence supports the benefits of physical activity (PA) for children's physical health, as indicated by cardiovascular and musculoskeletal health outcomes (Kristensen et al., 2010; Strong et al., 2005) and for their mental health, as shown by self-perception, emotional, and cognitive outcomes (Ahn & Fedewa, 2011; Biddle & Aasare, 2011). In the last decade, developmental researchers have devoted increasing attention to cognitive functioning as a relevant mental health outcome of PA and particularly to executive cognitive functions, which are responsible for self-regulation, goal-oriented and health-related behaviors (Tompo rowski, Davis, Miller, & Naglieri, 2008; Tomporowski, Lambourne, & Okumura, 2011).

While such evidence testifies the importance of PA at pediatric age, there is alarming evidence of secular decremental trends in children's PA levels (e.g., Dolmann, Norton, & Norton, 2005) and physical fitness test performance (e.g., Tomkinson, Leger, Olds, & Carzola, 2003) and an emergent health concern with 'exercise-deficit disorder' (Faigenbaum, Stracciolini, & Myer, 2011). Secular trends of decline have been also documented in children's coordination and fundamental motor skills proficiency (Raczek, 2002) with onset as early as at preschool age (Roth et al., 2010; Vandorpe et al., 2011), but research regarding these trends is still scarce and geographically limited. The scarce interest for secular trends in

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motor coordination at pediatric age is surprising if we consider the close interrelation existing between cognitive and motor development and, correspondingly, between the development of the brain substrates responsible for executive function and motor behavior (Diamond, 2000; Pennequin, Sorel, & Fontaine, 2010). Also from the perspective of atypical motor development, several decades of research have evidenced that children with severe motor clumsiness and impairments in motor control and perceptual-motor functioning (i.e., Developmental Coordination Disorder, DCD; American Psychiatric Association, 2000) have co-occurring cognitive and attentional problems (Kirby & Sudgen, 2007) and a strong association exists between DCD and deficits relying on executive function impairment (i.e., Attention Deficit Hyperactivity Disorder, ADHD) (Sergeant, Piek, & Oosterlaan, 2005).

As a consequence of the unbalanced attention devoted to secular trends in children's fitness and coordination, PA guidelines for young people scarcely consider aspects other than exercise quantity and fitness-related health. This represents a problem particularly in childhood that has been defined as 'skill hungry years' during which strongest emphasis should be put on PA experiences promoting motor and cognitive development (Kirk, 2005). This problem may also reflect the general lack of specificity in defining and measuring dimensions of PA for children from a qualitative point of view that goes beyond the framework of intensity, duration and frequency of activity (Dwyer, Baur, & Hardy, 2009).

Recently, it has been pointed out that this unbalanced interest for PA quality and quantity in favor of the latter extends to the area of exercise and cognition (Pesce, 2012). Also the attention of investigators working on the relationship between PA and cognitive function during development still mainly focuses on how the quantity of PA practiced by children and the resulting physical fitness affect children's cognition (Hillman, Erickson, & Kramer, 2008; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012). Instead, relatively little research has examined how the cognitive or social interaction demands of PA (Best, 2012; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) and its motor coordination demands (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow 2008; Gallotta et al., 2012) impact children's cognition independently of exercise intensity and duration (see Best, 2010 for a review). These studies, exclusively regarding the transient effects of a single bout of acute exercise, have lead to diverging results on the role of the amount of cognitive engagement by movement. Cognitive engagement or effort may be conceived as the allocation of limited resources to an ongoing task requiring mental operations and information processing. It is determined by executive processes that draw on mental resources, as when individuals perform novel or complex tasks requiring to consider multiple response pathways, but are only scarcely or not at all needed to perform repetitive responses that have been highly learned with extended practice (Tomporowski, McCullick, & Horvat, 2010). It remains to be tested whether cognitive engagement by complex and variable movement tasks in chronic exercise interventions may aid the development of executive functions in the preschool and primary school years in which such functions 'come online' (Garon, Bryson, & Smith, 2008; Huizinga, Dolan, & van der Molen, 2006).

This lack of developmental intervention studies in which the cognitive engagement in PA is manipulated by varying the cognitive and motor coordination demands of the physical exercise tasks is surprising. As a relevant review of interventions indicates (Diamond & Lee, 2011) executive function development can be aided in playful ways by mindfulness PA and sport practices, such as martial arts. However, attempts to deliberately apply executive function training by integrating specific cognitive demands into physical education (PE) games are still rare (Kubesch & Walk, 2009), as well as attempts to promote the development of executive function in children with motor developmental problems by capitalizing on the cognitive challenges of sport activities such as table tennis (Tsai, 2009).

The present study investigated the effects, on children's executive functions, of school-based PA interventions led by PE specialist teachers which either (1) included or (2) did not include additional cognitive demands specifically tailored to challenge executive function. Since in many countries PE in the early school years still is the responsibility of the classroom generalist teacher, we also assessed the cognitive outcomes of PE when it was (3) taught by generalist teachers. We verified whether the cognitive 'enrichment' of PA matches the ability/skill level of children with or without motor developmental problems. Since acute exercise studies in which the cognitive and coordinative complexity of the PA tasks was manipulated have shown diverging effects on executive function (Best, 2012; Budde et al., 2008; Gallotta et al., 2012; Pesce et al., 2009), we hypothesized that the 'dose' of cognitive and coordinative demands of the PA tasks may act as a moderator of the exercise–cognition relationship and that the emergence of cognitive benefits depends on the interplay between individual differences in motor development and amount of cognitive challenge in PA.

1. Methods

1.1. Participants

In the school year 2010/11, three kindergarten-primary schools of the Municipality of Rome (Italy) participated in the study. They belonged to similar urban districts and had a homogeneous socio–economic profile, as assessed using an area based measure. Within each school, seven gender-balanced classes (two kindergarten classes with children aged 3–5 years and five first to fifth grade classes with children aged 6–10 years) were selected according to teacher and class availability and randomly assigned to different PE programs. Since in the school setting, random assignment of individuals to different treatments is not feasible, we 'traded' the gold standard of fully randomized controlled trials for the ecological validity of school class settings. The parents of all participants provided informed written consent in conformity with the laws of the country and all children provided verbal assent before involvement in the study. The study protocol was approved by the institutional ethics committee.

Of the total 530 children involved in the intervention, 250 (127 male and 123 female) children aged 5–10 years, who were eligible for cognitive and/or motor coordination assessment, had no known diagnosed disorder of cognition and no physical condition hindering them to participate in a school PE program and did not miss any assessment session, represented the actual sample.

Baseline differences in PA levels and, given the young age of the children, differences in spontaneous outdoor play between children assigned to the different PE interventions may influence the intervention outcomes on cognitive functioning. Thus, outdoor play and PA levels were evaluated prior to the intervention period on a subsample of children ($n = 76$), stratified for schools and classes. Parents completed the Children's Outdoor Play Assessment Questionnaire (Veitch, Salmon, Ball, 2009) and older primary school children completed, under the supervision of the researchers, the Physical Activity Questionnaire for Children (PAQ_C) (Kowalski, Crocker, & Donen, 2004). No significant differences, as assessed by means of t-test for independent samples, emerged among children assigned to the three types of intervention (Table 1). Generalists and PE specialists volunteered in the study. The

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