Shifting the Focus From Quantitative to Qualitative Exercise Characteristics in Exercise and Cognition Research

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In exercise and cognition research, few studies have investigated whether and how the qualitative aspects of physical exercise may impact cognitive performance in the short or long term. This commentary, after recalling the evidence on the “dose-response” relationship, shifts the focus to intersections between different research areas that are proposed to shed light on how qualitative exercise characteristics can be used to obtain cognitive benefits. As concerns the acute exercise area, this commentary highlights the applied relevance of developmental and aging studies investigating the effects of exercise bouts differing in movement task complexity and cognitive demands. As regards the chronic exercise area, potential links to research on cognitive expertise in sport, functional ability in aging, and life skills training during development are discussed. “Gross-motor cognitive training” is proposed as a key concept with relevant implications for intervention strategies in childhood and older adulthood.

Keywords: acute exercise, chronic exercise, task complexity, executive function, life skills

In the last decades, the research area labeled exercise and cognition has experienced exponential growth. Early studies were characterized by a too general approach to this relationship. First attempts to synthesize available evidence, merging acute and chronic exercise studies, concluded that research was mainly atheoretical and called for well-designed studies to help reduce ambiguity of conclusions (Tomporowski & Ellis, 1986; Etnier et al., 1997). Later, exercise and cognition research has been grounded in current theories of brain functioning and attention has been narrowed to specific aspects of the exercise–cognition relationship. Both acute and chronic exercise research show such trends toward specificity. This allowed the identification of the selective nature of physical exercise effects on cognition (Etnier & Chang, 2009) and potential mediators and moderators acting on this relationship (Spirduso, Poon, & Chodzko-Zajko, 2008; Tomporowski, Lambourne, & Okumura, 2011). (A mediator is a generator mechanism through which

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physical exercise influences cognitive functions, whereas a moderator is a variable that influences the direction and/or strength of the exercise–cognition relationship.)

In chronic exercise research, the hypothesized mediating mechanisms include cardiovascular fitness, cerebral structure and circulation, and neurotrophic stimulation (Etnier, 2009a; Hillman, Erickson & Kramer, 2008). Higher functional connectivity in neural networks (Voss, Erickson, et al., 2010) and greater gray matter volume in the prefrontal cortex (Weinstein et al., 2011) seem to mediate the relationship between cardiovascular fitness and cognition, thus supporting the existence of mediational chains (Etnier, 2008). In acute exercise research, main putative mediators from a cognitive-psychological perspective are changes in arousal and in resources allocatable to cognitive tasks, while from neuroscientific and psycho-physiological perspectives, the hypothesized mediators include exercise-induced increases in catecholamines and neurotrophic factors (Audiffren, 2009; Dietrich, 2009; Ferris, Williams, & Shen, 2007; Lambourne & Tomporowski, 2010; McMorris, 2009).

Researchers have also identified the moderating role played by the features of the physical exercise task, the type of cognitive performance, and the characteristics of the participants. The most investigated exercise parameters are quantitative in nature: in acute exercise research, they are intensity and duration of the exercise bout, whereas in chronic exercise research, further relevant parameters are physical training frequency and intervention length. The main differentiation in cognitive performance assessed is between tasks tapping higher-level cognitive functions, the executive, and nonexecutive tasks, with increasing interest for the first (Etnier & Chang, 2009). Relevant individual characteristics moderating the acute exercise–cognition relationship are age, gender, and physical fitness (Chang, Labban, Gapin, & Etnier, 2012) and, even though less investigated, individual differences in sport-specific cognitive expertise and motor coordination skills (Pesce, 2009).

In both acute and chronic exercise research, there has been a prevalent focus on moderation or mediation accounted for by the “quantitative” parameters of the physical exercise and its physiological consequences. This focus on quantitative parameters likely reflects the predominant “medical” perspective from which researchers generally examine dose-response relations between physical activity and health outcomes to derive prescription guidelines (e.g., Bouchard, 2001; Lee, 2008). Recently, the position stand of the American College of Sports Medicine (Garber et al., 2011) underlined the need for considering both quantity and quality of exercise for health promotion. Nevertheless, evidence on the former still largely prevails over the latter. The fact that the role played by “qualitative” exercise aspects still remains underinvestigated may also be a consequence of the difficulty in operationalizing the breadth of the exercise quality construct.

The qualitative characteristics of exercise are globally defined as exercise type or mode (Garber et al., 2011). However, they represent a set of different non-physical aspects of exercise tasks, including the cognitive or coordinative demands inherent in movement and sport tasks at a greater or lesser degree. In exercise and cognition research, exercise mode is still grossly considered as the type of activity performed (e.g., running vs. bicycling; Lambourne & Tomporowski, 2010) or in terms of metabolic and neuromuscular demands (e.g., muscular strength/resistance exercise vs. aerobic exercise; Voss et al., 2011). A qualitatively broader range of physical exercise modes have been examined in developmental research.
(e.g., aerobic, resistance, perceptual-motor training or their combination; Fedewa & Ahn, 2011), but the frequent covariation of quantitative and qualitative exercise features limits the possibility to differentiate their individual impact on cognition. Therefore, it has been recently claimed (Hill et al., 2010) that we need to explore whether exercise effects on cognition may differ as a function of the coordinative and cognitive complexity of the movement tasks.

This commentary focuses on the need, in both acute and chronic exercise-cognition research, to think beyond the framework of the quantitative parameters of physical activity. There still is a paucity of evidence on whether and how the qualitative aspects of physical exercise may impact cognition (e.g., Best, 2010; Tomporowski, Davis, Miller, & Naglieri, 2008). The wide variability in how exercise quality can be defined is relevant to this issue because the specific definition used to guide research influences the ability to further our understanding of the relationship between exercise and cognition. To shed light on how physical exercise quality can be exploited to reap cognitive benefits, we need to develop interdisciplinary evidence intersecting different lines of research.

Quantitative Exercise Characteristics and the Dose–Response Relationship

Acute Exercise Research

In acute exercise research, a main distinction is between “in-task” and “off-task” exercise research in which physical exercise is concomitant with or antecedent to cognitive task performance, respectively. In both cases, the quantitative parameters of exercise and especially intensity have been manipulated to implicitly or explicitly test the dose–response relationship (e.g., Chang & Etnier, 2009). In an earlier meta-analysis, Etnier et al. (1997) did not find any moderation of acute exercise effects by exercise intensity. This lack of effect for intensity was confirmed in a more recent meta-analysis of studies spanning from childhood to old adulthood, but only when exercise bouts were concomitant with cognitive performance (Chang et al., 2012). Instead, a positive effect for cognitive performance during steady-state exercise, but a negative effect for incremental and fatiguing exercise, emerged in a meta-analysis of young adult studies (Lambourne & Tomporowski, 2010). These reviews suggest that the existing evidence does not generally support the inverted-U hypothesis, according to which cognitive performance would improve with increasing exercise intensity and exercise-induced arousal up to an optimal point and then degrade with further arousal increments. Although individual studies have supported the inverted-U hypothesis (e.g., Arent & Landers, 2003; Chmura, Nazar, & Kaciuba-Uscilko, 1994), other studies suggest that the function describing the effect of exercise intensity on cognition varies depending on the type and complexity of the cognitive functions measured, with moderate intensity being most beneficial to executive function, whereas maximal and even supramaximal intensities to processing and movement speed (Chang & Etnier, 2009; McMorris et al., 2005). The hypothesis, related to the inverted-U function, that increments in plasma catecholamine concentrations induced by increasing exercise dose would have a direct effect on cognition (i.e., catecholamine hypothesis) was not confirmed in a study by McMorris, Collard, Corbett, Dicks, and Swain (2008).
Consequently, McMorris (2009) proposed a more complex neuroendocrinological model as a more appropriate framework to reconcile inconsistent findings on the dose–response relationship.

The pattern of moderation by exercise intensity is different when the physical exercise is antecedent to the cognitive task. Cognitive performance seems to be facilitated by lower exercise intensities immediately after exercise, but by higher intensities after a delay (Chang et al., 2012). The authors argued that different physiological mechanisms may subtend the different ways in which intensity moderates acute exercise effects at different times after the exercise bout.

Further theoretical approaches with potential implications in terms of a dose–response relationship are resource allocation theories and cognitive-energetic models (Audiffren, 2009). They are grounded on the assumption that cognitive performance is dependent on the allocation of energetical resources through mental effort and that acute exercise influences brain systems responsible for such allocation. Acute exercise bouts seem to be responsible for more effective (Audiffren, 2009) or ineffective resource allocation (“hypofrontality hypothesis” by Dietrich, 2009) depending on the type, complexity, and timing of the cognitive task. Nevertheless, to date, no inference about a dose–response relationship is possible because almost all studies of acute exercise effects on more complex cognitive tasks were conducted only with intermediate exercise intensities (McMorris, Sproule, Turner, & Hale, 2011).

Additionally, individual differences in fitness level seem to influence the cognitive response to exercise dose. Etnier et al. (1997) had reported largest effect size from the few studies combining acute and chronic exercise designs, which suggested that physical fitness positively influences the response to higher exercise doses (Pesce, 2009). This was confirmed by Chang et al. (2012): acute exercise effects on concomitant cognitive performance of highly, moderately, or low fit participants were positive, negligible, and negative, respectively. The advantage of being physically fit seems to be limited to physical-cognitive dual tasking conditions, since a different pattern of moderation or no moderation at all emerged when cognitive performance was assessed after the exercise bout.

How efficiently the resources available during physical exercise are allocated to an ongoing cognitive task may also depend on cognitive expertise acquired through the practice of cognitively challenging sports (Pesce, 2009). For instance, cognitively expert athletes showed higher psychomotor speed at higher exercise intensities when performing both sport-specific (McMorris & Graydon, 1996) and unspecific cognitive tasks (Delignières, Brisswalter, & Legros, 1994), whereas cognitively less experienced athletes showed no dose–response relationship or an opposite, decremental trend of psychomotor performance with increasing physical exertion, respectively.

**Chronic Exercise Research**

In a systematic review, Etnier (2009b) asked if we have accumulated sufficient evidence to be ready for physical activity programming targeted to obtain cognitive benefits. She concluded that although we are ready to generally recommend increasing physical activity levels, more research from a dose–response perspective is needed to identify optimal exercise intensity, duration, and frequency. This call for further research to gain insight into the dose–response relationship with regard
to quantitative parameters is present in aging literature (e.g., Kramer, Erickson, & Colcombe, 2006), as well as in a recent developmental review (Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012).

The existing evidence derives from noninterventional and interventional prospective studies. Noninterventional, large-scale prospective studies have been almost exclusively conducted with older adults to verify whether the quantity of physical activity practiced, translating into a corresponding level of energy expenditure (Middleton et al., 2011), and the individual physical fitness level are predictive of less age-related cognitive decline over time (Etnier, 2009b). In intervention research, the dose of physical activity has been manipulated in terms of session duration (e.g., Davis et al., 2011), frequency of weekly sessions (e.g., Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2011), and length of the training program (e.g., Voss, Prakash, et al., 2010). More research with varying exercise intensity is still needed, since intensity has been manipulated in covariation with exercise type (e.g., aerobic training vs. stretching, Colcombe et al., 2004) mostly in aging (Etnier, 2009b) and only rarely in developmental research (Davis et al., 2011). Also, until recently, the dose–response relationship has been mainly investigated by means of aerobic exercise interventions focused on the linkage between aerobic exercise, cardiovascular fitness, and cognitive function (Hillman et al., 2008). Nevertheless, growing evidence suggests that resistance training is important for maintaining cognitive and brain health in aging, and this suggests a need for the investigation of more differentiated types of exercise interventions (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011).

On the whole, conclusions about the dose–response relationship are rendered difficult by the diverging evidence from noninterventional and interventional prospective studies. Noninterventional prospective studies suggest that older adults who maintain or increase physical activity intensity and duration over time do not show the cognitive decline observed in co-aged individuals who reduce their physical activity level (Etnier, 2009b). In contrast, intervention studies suggest that moderate, not long exercise duration exerts optimal effects on cognition of aging people (Colcombe & Kramer, 2003). However, this meta-analytic result may be biased by the fact that the moderating role of exercise duration is not “pure,” but may partially overlap with other moderators acting on the exercise–cognition relationship (Etnier, 2009b).

A further divergence regards the associations between physical activity, fitness level, and cognitive functioning. According to noninterventional prospective studies, higher levels of physical activity and cardiovascular fitness are predictive of higher cognitive efficiency in old (Middleton et al., 2011) and young adulthood (Åberg et al., 2009). A large amount of interventional aging studies, commonly employing aerobic exercise training, entail the assumption that gains in aerobic fitness would mediate the cognitive benefits observed after a period of physical training (i.e., cardiovascular fitness hypothesis). However, this mediation hypothesis is primarily grounded on piecemeal evidence regarding physical activity effects on aerobic fitness and aerobic fitness effects on cognitive functioning (Etnier, 2009b). Both recent empirical studies (e.g., Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008) and meta-analytic reviews failed to give support to the cardiovascular fitness hypothesis in the general (Etnier et al., 2006) and in the aging population (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Chronic participa-
tion in physical activity per se, independently of exercise-induced improvements in aerobic fitness, might be responsible for such benefits. These divergences call for research aimed to clarify the specific nature of exercise effects on cognition to understand the mechanisms underlying dose–response relations (Etnier, 2009b).

**Extending the Notion of a Dose–Response Relationship**

Recently, exercise and cognition researchers have started investigating the effects of exercise modes different from aerobic, but evidence is still scarce in both chronic (except see Voss et al., 2011) and acute exercise research (except see Chang & Etnier, 2009; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). Intriguing aging studies allow extending the notion of selectivity of exercise effects on cognition from aerobic exercise (e.g., Smiley-Oyen et al., 2008) to resistance training (Liu-Ambrose et al., 2011), mind–body exercises (Matthews, & Williams, 2008), and coordination training (Voelcker-Rehage, Godde, & Staudinger, 2011). The latter neurophysiological findings suggest that aerobic and coordinative training improve cognition through different underlying mechanisms. Further, as concerns the beneficial effects of mind–body exercises on cognition, potential mediators different from aerobic fitness gains, such as physical resources (e.g., sleep effectiveness), mental resources (e.g., self-efficacy), and disease states (e.g., hypertension) have been suggested on the basis of indirect evidence (Chang, Nien, Tsai, & Etnier, 2010). This supports the hypothesis that cardiovascular fitness gains or other metabolic or neurochemical mechanisms influencing the integrity of the neural “hardware” may not be the only mediators of physical exercise effects on cognitive functioning. Exercise-related cognitive benefits may also be due to neural stimulation by the coordinative and cognitive complexity of the movement tasks, which influences the efficiency of the brain “software” (Davis et al., 2011). However, the major limitation of the evidence from multicomponent interventions joining physical and “mindfulness” activities is that information to control for intensity, frequency, duration, or intervention length is scarce. Therefore, to gain new insights into the exercise–cognition relationship, it is necessary to integrate research on the role played by exercise intensity, duration, and frequency with novel research focusing on qualitative, nonphysical characteristics of exercise tasks.

Furthermore, recent acute exercise research showed diverging results on whether the coordinative and cognitive complexity of the exercise task is beneficial to cognitive function (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) or not (Gallotta et al., 2011; O’Leary, Pontifex, Scudder, Brown, & Hillman, 2011). Apart from methodological differences that are addressed later, these divergences might be reconciled by controlling whether the “dose” of coordinative and cognitive demands of the physical exercise task moderates the effect of exercise on cognition also accounting for age and individual skill level. The notion of dose and response should therefore be extended from the research line centered on the moderating role of exercise intensity, duration, and frequency to the novel line focused on the role played by the coordinative and cognitive complexity of the physical exercise task.

The coordinative and cognitive task requirements can be embedded into the theoretical framework proposed by Wood (1986) in the general study of tasks as factors individually and jointly contributing to overall task complexity. In fact, he
proposed to combine the frameworks of (1) “task as behavior requirements” and (2) “task qua task,” providing a feasible operationalization of tasks as (1) behavioral responses involving motor activities and/or cognitive processes and (2) patterns of stimuli impinging on the individual. The relationship between behavioral responses and stimulus complex for a task represents a type of task complexity that can be operationalized manipulating the coordinative and cognitive task requirements.

Thinking Beyond the Framework of Intensity, Duration, and Frequency

The Role of Physical Task Complexity in “In-Task” Exercise Research: Evidence From Motor-Cognitive Dual Task Studies

Dual task methods in which a cognitive task is performed simultaneously with a task requiring motor activity may help understand whether a qualitative aspect of movement tasks—their coordinative complexity—impacts cognition. This issue has been investigated by both acute exercise researchers (Brisswalter et al., 2002) and motor coordination researchers (Monno, Temprado, Zanone, & Laurent, 2002), but with different foci of interest. Acute exercise researchers (reviewed in Brisswalter et al., 2002) have manipulated the movement execution frequency (i.e., pedaling rate) focusing on whether the different energetic demands of different frequencies influence a concomitant cognitive performance. Because, however, physical exercise bouts of similar intensity elicited diverging effects on cognition depending on whether movement execution frequency was externally paced or freely chosen, Davranche and Audiffren (2004) argued that the freely chosen execution frequency had the cognitive advantage to require lower demands on attentional monitoring.

Conversely, motor coordination researchers have jointly manipulated qualitative (coordination mode, frequency) and quantitative (intensity, duration) aspects of the movement tasks to evaluate the mental costs of motor coordination (e.g., Murian, Deschamps, & Temprado, 2008). Both exercise and cognition researchers (Davranche & Audiffren, 2004) and motor coordination researchers (Zanone, Kostrubiec, Albaret, & Temprado, 2010) have pointed out that individual differences in motor coordination skills moderate the effects of physical exercise on a concomitant cognitive performance (Pesce, 2009). These commonalities suggest that an integrative approach might help further our understanding of the role played by the qualitative characteristics of physical exercise tasks.

The interplay between concomitant motor and cognitive tasks related to one’s individual skills acquires practical relevance in aging. In fact, everyday life situations often require the simultaneous performance of multiple motor-cognitive tasks, but age-related losses of both interlimb coordination and attentional control resources challenge the ability to cope with such situations (Schaefer & Schumacher, 2011). An issue of debate is whether older people prioritize motor control by withdrawing capacity-limited resources from a concomitant cognitive task or, vice versa, prefer protecting cognitive functioning by “paying” with some motor control resources. Prioritizing the motor domain seems to apply to older adults (Li, Lindenberger, Freund, & Baltes, 2001) as well as to children (Schaefer, Krampe, Lindenberger, & Baltes, 2008) when highly demanding maintenance of balance and functional
locomotion is required (“posture first” hypothesis). There is also counterintuitive evidence that motor-cognitive dual task situations may lead to performance increments in older adults up to a given level of cognitive effort (Huxhold, Li, Schmiedek, & Lindenberger, 2006). The interpretation proposed for these findings (i.e., “dual-process account”), is that a low-difficult concurrent cognitive task may induce an external attentional focus allowing the motor system to better self-organize, while with increasing cognitive task difficulty, performance would be worsened by an excessive withdrawal of resources from motor control.

The Role of Physical Task Complexity in “Off-Task” Acute Exercise Research: Evidence From Ecological and Laboratory Studies

Physical task complexity has been considered in “off-task” acute exercise research, in which cognitive performance was measured following exercise. However, only a few studies, discussed in this section, have controlled for equality in exercise intensity and duration (see Best, 2010 for a review). Budde et al. (2008) compared the effects of coordinatively more or less complex aerobic exercise bouts on executive attention of adolescents in the school setting and found more pronounced benefits after the more complex exercise task. Gallotta et al. (2011) extended this test protocol to preadolescent children and compared the effects of a traditional or a coordinatively enriched physical education lesson, but found benefits only in the case of the traditional lesson. Budde et al. (2008) interpreted their results in terms of facilitation of neuronal networks involved in complex motor coordination, while Gallotta et al. (2011) referred to older theories of exercise as a stressor and argued that the coordinatively engaging exercise mode would elicit excessive increases in arousal translating to poorer attentional performance. Also, O’Leary et al. (2011), in a study conducted with adults in a laboratory, found that a cognitively high-engaging bout of aerobic exercise (a virtual reality game involving physical activity, or “exergaming”) did not facilitate attentional performance, whereas simple treadmill running did. Nevertheless, the different age class and experimental conditions make it difficult to provide a cogent explanation of these results.

A means through which the qualitative, nonphysical demands of a physical exercise task can be quantified to identify the appropriate “dose” of physical task complexity to gain cognitive benefits is to categorize motor behaviors based on standardized observation systems (e.g., Rink, 2006). Such classification was provided in only one study with preadolescents aimed at investigating the after-effects of qualitatively different physical education lessons (team sport games vs. circuit training) on memory recall performance (Pesce et al., 2009). On the one side, the results confirmed the general arousing effect of acute exercise that translates into better memory performance independently of the type of physical exercise tasks. On the other side, they showed that team games caused additional memory recall benefits. This is presumably due to the cognitive challenges inherent in the group interactions and strategic application of motor skills that were more frequently observed in team sport games than in circuit training. These kinds of findings suggest that the qualitative characteristics of sport activities may represent a relevant factor impacting on the exercise–cognition relationship.
Crossing Chronic Exercise and Cognitive Expertise Research

Cross-sectional chronic exercise research and sport expertise research have developed on separate tracks with different basic and applied research purposes. Chronic exercise researchers mainly focus on the search for biophysiological mediators underlying physical activity effects on cognition and on the applied relevance for promoting healthy brain development and aging (e.g., Colcombe et al., 2004; Tomporowski et al., 2011). Sport expertise researchers, instead, are primarily interested in perceptual-cognitive expertise and in the identification of the mediating mechanisms that account for expert performance with the aim to detail how to promote their development in sports training (e.g., Mann, Williams, Ward, & Janelle, 2007; Moran, 2009). A further difference is the level of domain generality/specificity of the observed impact on cognitive functioning. Chronic exercise research has mainly shown beneficial exercise effects on domain-general, high-level cognition and particularly on executive function (e.g., Etnier & Chang, 2009). In contrast, the “expert performance approach” has highlighted that extensive sport practice is associated with superior performance on tasks embodying domain-relevant constraints and requiring sport-specific cognition (Williams & Ericsson, 2005). This supports the narrow transfer hypothesis, suggesting that individuals who are experienced in activities such as team sports only differ from inexperienced people in cognitive skills that are relevant to their field (Furley & Memmert, 2011). A minority of studies belonging to the “cognitive component skills approach” (Voss, Kramer, et al., 2010, p. 813), in contrast, suggest that skilled athletes practicing strategic sports may have superior performance also on sport-unspecific tasks requiring fundamental cognitive abilities (e.g., Pesce, Cereatti, Casella, Baldari, & Capranica, 2007; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). This supports the broad transfer hypothesis, suggesting that practice in a specific activity can also lead to adaptations in basic cognitive abilities that are therefore transferable to other domains (Furley & Memmert, 2011).

Despite these differences, chronic exercise and sport expertise research areas also show intriguing commonalities. A novel line of individual difference research is emerging at their intersection point with the aim to explore the interplay between cognitive skill and physical fitness outcomes of habitual participation in strategic sports (Voss, Kramer, et al., 2010). Chan, Wong, Liu, Yu, and Yan (2011) investigated the efficiency of cognitive inhibitory functions in individuals differing in sport-related cognitive expertise (fencers vs. nonfencers) and physical fitness level (high-fit vs. average-fit) and found that inhibition was best in high-fit fencers. However, the most interesting result for the aim of the present discussion is that average-fit fencers and average-fit nonfencers did not show cognitive performance differences. Speculatively, there may be a threshold for the biophysiological mechanisms mediating physical exercise effects on cognition below which the exploitation of the mechanisms mediating expertise effects on cognition is not possible, or at least not optimal. This fits with the hypothesis, derived from animal studies, that physical exercise would increase neural activity in specific brain structures (Anderson, McCloskey, Mitchell, & Tata, 2009) and prepare the potential for neurogenesis that can be better exploited if exposed to cognitive enrichment (Fabel et al., 2009).

Cognitive task complexity and diversification of motor activities are forms of enrichment whose relevance has been recognized also in developmental sport...
expertise research. Studies analyzing the physical activity and sport background of top-level athletes practicing team/racket sports indicated a history of early diversification during the developmental years that, particularly when including other mentally demanding sports, augmented the cognitive skills necessary in the primary sport (Baker, 2003). In addition, those athletes who spent more time in diversified, unstructured play activities in early youth showed more pronounced skills in sport-specific creative thinking (Memmert, Baker, & Bertsch, 2010). Therefore, there seems to be a transfer of cognitive skills to sport-specific tasks coming from unspecific and diversified activities. To exploit the potential of sports training for promoting cognitive efficiency in the general, developing, and aging population, we also need interventional evidence of a “cross-training” effect in the opposite direction.

**Merging Physical and Cognitive Training Into Gross-Motor Cognitive Training**

In aging research, both earlier (e.g., Tomporowski, 1997) and recent (e.g., Jak, 2011) reviews testify to an interest for both physical and cognitive training effects on cognitive efficiency. Unfortunately, most of these studies employed either physical or cognitive training interventions that did not combine physical and cognitive activities, as evidenced in the narrative reviews by Schaefer and Schumacher (2011) and Thom and Clare (2011). The rare studies employing combined training showed that it induced greater benefits than either physical or cognitive training in isolation (Fabre, Chamari, Mucci, Massé-Biron, & Préfault, 2002; Oswald, Gunzelmann, Rupprecht, & Hagen, 2006). Combined cognitive-motor interventions of very short length seem to benefit the cognitive functioning of aging people, but those benefits have not been contrasted with the effects of separate physical or cognitive training interventions (Benloucif et al., 2004; Small et al., 2006). Moreover, all these studies combined physical and cognitive training only in sequential fashion. Instead, Schaefer and Schumacher (2011) have described a sound experimental design to compare the effectiveness of physical and cognitive training programs in single fashion, or combined in counterbalanced order, or merged in the form of integrated physical-cognitive dual tasks (e.g., verbal working memory tasks while walking on a treadmill). Anderson-Hanley et al. (2012) recently demonstrated better cognitive outcomes of stationary cycling with virtual reality tours than traditional exercising of similar effort and fitness outcomes. Positive cognitive outcomes have also been obtained through coordination training (Voelcker-Rehage et al., 2011) and nonaerobic movement-based activity programs challenging attentional and mnemonic processes (e.g., Yáñez, Shaw, Morris, & Matthews, 2011). A further promising perspective is that proposed by Chang et al. (2010), who reviewed the literature on the effects of Tai Chi Chuan, a type of mind–body physical activity joining the characteristics and mindfulness of the martial arts and the philosophy of Tai Chi, on cognitive function in aging.

These findings suggest that the engagement of cognitive functions during physical activity, that is, a sort of “gross-motor cognitive training,” can be an important factor for old people to obtain cognitive benefits. In cognitive training research, there is increasing evidence that tasks demanding executive coordination of skills train cognitive control abilities that transfer to more remote domains (Hertzog, Kramer, Wilson, & Lindenberger, 2009; Zelinski, 2009). This suggests that gross-motor
cognitive training should be specifically shaped to challenge executive functions by movement. Thom and Clare (2011) and Voss et al. (2011) claimed that also clinically significant outcomes, such as functional mobility and quality of life, should be included to bridge the gaps between neuroscientific, behavioral, and clinical gerontology. Recent evidence showed that multicomponent cognitive-motor interventions combining strength, balance, and complex coordinative exercises can improve step execution under single- and dual-task conditions in older adults (Pichierri, Coppe, Lorenzetti, Murer, & de Bruin, 2012). Future research should investigate what qualitative exercise characteristics specifically promote executive function improvements and to what extent the latter translate into functional ability, that is, the ability to safely and effectively perform daily tasks and commonly refers to gross lower limb locomotor task performances. This kind of clinical intervention research may have relevant implications for practitioners involved in promoting late-life mobility and independence.

In a developmental review, Best (2010) proposed that, apart from the bio-physiological changes induced in the brain by the metabolic demands of physical activity, there may be at least two further pathways by which physical activity impacts high-level cognition: the cognitive effort required to perform complex movement tasks and the cognitive demands inherent in mindfulness and open-skill sport practices. Interesting intervention studies involving the manipulation of the cognitive task demands have been conducted in youth sports training to promote children’s creativity. It emerged that diversified sport enrichment programs led to the development of sport-relevant creative thinking and that individual differences in giftedness moderated the intervention effects (Memmert, 2006). The degree of transferability of creative thinking skills acquired through sports training is still unclear. The available evidence supports the notion of transfer between different subdomains (i.e., between various team/racket sports, Memmert & Roth, 2007), but not that of transfer to general creative thinking (Memmert, 2011). This type of research has the merit to provide a unique basis for a convergence of expertise and creativity research. Moreover, there seems to be a complex interplay between creativity in thought and action and executive function (Scibinetti, Tocci, & Pesce, 2011). Thus, the creativity construct represents a potentially relevant intersection point between research on cognitive sport expertise and research on the qualitative characteristics of exercise affecting high-level cognition.

Further evidence on the relevance of qualitative exercise characteristics derives from studies on coordinative complexity and cognitive effort in motor skill learning (Carey, Bhatt, & Nagpal, 2005). The cognitive effort needed to cope with complex learning tasks seems to be essential to produce the neuroplastic changes underlying skillful motor performance. Since physical exercise is composed of movement-based tasks, a way to reap large cognitive benefits from physical training might be that of maintaining a sufficiently high degree of coordinative task complexity and novelty relative to age and skill level. Motor learning has been explained in terms of stage-like progression toward automaticity and autonomy that begins with a cognitive stage requiring mental engagement (Schmidt & Wrisberg, 2004). To promote cognitive development, it has been therefore proposed to employ movement games that keep children “on the learning curve” and to exploit criteria of variability of practice in motor learning placing cognitive demands on learners, such as contextual interference (Tomporowski, McCullick, & Horvat, 2010). This
proposal is based on the potential of action to affect cognitive development (Rakison & Woodward, 2008), especially during the sensitive periods in the development of brain structures subtending high-level cognitive function (executive function) (Thomas & Johnson, 2008).

**Bridging Gross-Motor Training of Executive Functions and Life Skills Training**

Since executive functions are cognitive prerequisites of self-control, behavioral adaptability, and academic achievement, they have received much attention in developmental research (Garon, Bryson, & Smith, 2008; Huizinga, Dolan, & van der Molen, 2006). A relevant review of interventions aiding executive function development (Diamond & Lee, 2011) highlighted that both computerized cognitive training and aerobic physical exercise can be effective approaches already in early education. Based on this evidence, Kubesch and Walk (2009) have developed an intriguing playful program of integrated physical-cognitive training for children. Future research should investigate what types of movement-based games are appropriate according to the differential developmental trajectories of the diverse executive functions (Garon et al., 2008; Huizinga et al., 2006). Manipulating the “dose” of coordinative and cognitive demands can help identify what are optimal challenge points during childhood. Executive functions must be continually challenged to promote improvements. Children who perform the same activities, but do not experience challenge because there are no increments in task difficulty, do not gain in executive functioning (Diamond & Lee, 2011).

Gross-motor training of executive functions differs from computerized training in that cognitive challenges are embedded into physically and socially engaging playful activities. This is an advantage, since to improve executive functions, focusing narrowly on either cognitive stimulation or physical activity in isolation seems not to be as effective as when cognitive, physical, emotional, and social development are addressed jointly. This is one of the relevant conclusions drawn by Diamond and Lee (2011) when synthesizing evidence from the different approaches employed to aid executive function development. This advantage of movement-based multicomponent interventions involving self-regulation training and mindfulness practices to promote cognitive functioning has been highlighted not only in developmental research, but also in aging research evaluating the effectiveness of multidomain mind–body practices (Chang et al., 2010; Wayne & Kaptchuk, 2008). One of the most intriguing developmental studies is that performed by Lakes and Hoyt (2004), who showed that tae-kwon-do training caused greater gains in children’s executive functions than standard physical education and such gains generalized to multiple contexts. According to Diamond and Lee (2011), several aspects of the tae-kwon-do intervention may have led to such cognitive benefits. First, it joined cognitive (self-regulation, inhibition) and affective (quitting/persevering) demands. Second, the program addressed several executive function components that were continuously stimulated with challenge incrementing—a necessary condition to obtain executive function gains. Third, it included questions to the children (i.e., inquiry teaching strategy) promoting self-monitoring and goal setting that are typical for life skills training strategies. Therefore, this type of multicomponent intervention merged—even though implicitly—gross-motor training of executive functions and life skills training.
The World Health Organization (1994) has described life skills as intra- and interpersonal skills, including creativity, empathy, interpersonal relationship skills, and goal-setting skills that enable individuals to self-regulate behaviors and deal effectively and adaptively with everyday life demands. Therefore, life skills training is recommended as an effective means to enhance self-regulatory competence and reduce risk behaviors in youths. A relevant commonality of life skills and executive functions is that both play a key role in behavioral self-regulation. The latter in turn has cognitive and emotional components with a common substrate in the frontal lobe, which is also the primary substrate of executive functions (Posner, Rothbart, Sheese, & Tang, 2007). This commonality, however, still remains unconsidered in sport and exercise research. One reason for this lack of integration may be that life skills interventions are grounded on psycho-social and social-cognitive theories different from the theoretical underpinnings of exercise and cognition research.

Sports training and physical education have been shown to be appropriate environments for life skills training with positive sport performance outcomes (Danish, Hodge, Heke, & Taylor, 2003; Goudas, 2010). An outlook for future research on life skills training through sport calls for studies designed to identify theoretical explanations for life skills development (Gould & Carson, 2008), but does not mention the potential interrelation between executive functions and life skills development. On the other side, there are not yet developmental intervention studies aimed at testing the benefits of sports for executive functions. Life skills training programs may offer a basis to shape sport-based programs that aid executive function development. In fact, such life skills as goal setting, planning, and problem solving, which are obviously linked to executive function and have the potential to enhance performance both in sport and in other settings, have been successfully taught with movement-based and sport-based life skill programs (Goudas, Dermitzaki, Leondari & Danish, 2006; Goudas & Giannoudis, 2008). Future research should investigate the benefits that might be obtained by integrating cognitively challenging physical exercise and life skills training in sports and physical education settings.

Conclusions

This commentary aimed at offering new suggestions for research that can further our understanding of the exercise–cognition relationship and its implications for physical activity and sports practice. The key point is that we need to complement research on the moderating role of the quantitative characteristics of physical exercise with novel research investigating the role of its qualitative characteristics, such as coordinative complexity and cognitive demands. This issue has been examined here from theoretical and applied perspectives on both acute and chronic exercise effects.

In acute exercise research applying the dual task methodology, intersections with motor coordination research can help understand the role played by the coordinative complexity of physical exercise tasks. This issue has practical implications for aging people, since age-related losses of motor coordination and cognitive control challenge their dual-tasking ability. The role of physical task complexity in the exercise–cognition relationship also emerges from developmental research on the after-effects of acute exercise with relevant implications for learning contexts.
As concerns chronic exercise research, intersections with sport expertise research can offer insights into the interplay between physical fitness and cognitive expertise outcomes of sport participation. The commentary also focuses on the cognitive benefits deriving from training interventions that integrate coordinative and cognitive challenges into physical fitness training.

A new concept of “gross-motor cognitive training” shaped to challenge executive function by movement is proposed and discussed referring to emerging evidence from aging and developmental intervention studies. In youth sports research, intriguing studies joining expertise and creativity research provide a unique basis to develop research on how the qualitative characteristics of exercise affect high-level cognition. Useful insights can also derive from motor learning research dealing with task complexity and cognitive effort. In educational research, the most promising perspective is that of multifaceted interventions that aid executive function development, joining cognitive, physical, and affective demands. This holistic perspective suggests potential links between gross-motor training of executive functions and life skills training through sport and physical education.

In conclusion, gross-motor cognitive training represents a potential means to capitalize on the cognitive benefits of participation in physically effortful and mentally engaging activities. The related challenge will be to identify what “dose” of coordinative and cognitive demands of physical tasks is appropriate to reach the optimal challenge point and gain greatest cognitive benefits according to age and individual skill level. An integrative view on the qualitative and quantitative characteristics of physical exercise training aiding executive function development and maintenance represents a key element for an evidence-based model of quality physical activity to inform policy development.

References


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