Educ Psychol Rev
DOI 10.1007/s10648-015-9323-5

COMMENTARY

Brains and Brawn: Complex Motor Activities to Maximize Cognitive Enhancement

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Abstract The target articles in this special issue address the timely question of embodied cognition in the classroom, and in particular the potential of this approach to facilitate learning in children. The interest for motor activities within settings that typically give little space to nontraditional content is proof of a shift from a Cartesian dichotomy to a united approach of brain and body, particularly in line with recent advances in neuroscience. In this commentary, I discuss some of the possibilities offered by a blend of cognitive and motor demands in the context of cognitive enhancement. I then present novel empirical evidence and current trends of research that support this approach, and discuss examples of effective cognitive training interventions based on motor activities. Ultimately, the rationale for an early start to a successful and healthy education goes beyond the classroom—the goal is to educate the next generations about the benefits of sustained motor activities across the lifespan.

Keywords Cognitive enhancement · Cognitive training · Physical exercise · BDNF · Complex motor learning · Embodied cognition · Integrated interventions · Education

The recent growth in the number of people affected by cognitive disorders has underlined the central role our brains play in daily life. Once our sophisticated neural machinery is impaired, we come to realize how important normal cognitive functioning really is. Together with growing evidence for the malleable property of the brain, this heightened awareness drives the current trend of research based on behavioral training programs that can remedy or alleviate cognitive disorders. As a result, more and more individuals enroll in brain training programs or subscribe to brain fitness apps, all promising meaningful enhancement in cognitive performance.

In parallel with this societal trend, the field of education is being massively impacted by the promises of cognitive enhancement. Students experience tremendous pressure to achieve at

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Published online: 07 July 2015

school and on standardized tests, and college admissions, once concerns of high school students alone, can now be compromised by performance in primary school. In several places in the USA, the competition is so fierce that parents have to go through interviews to secure a spot for their child in preschool—some are even dressing them up in business attire, tie included (Rafsanjani 2011).

Such behaviors are extreme, yet they reveal a genuine pressure and a growing demand for effective means to enhance school performance. It has been suggested that one in five college students consumes cognitive enhancing medication usually prescribed for conditions such as attention-deficit/hyperactivity disorder (ADHD, e.g., Adderall, Ritalin) to boost academic performance (Dietz et al. 2013), although additional evidence indicates that this ratio might be a slight overestimation (Bossaer et al. 2013). Regardless of the precise estimate of users, this trend toward self-medication is serious enough to require regulations (Ragan et al. 2013) and focused information disclosing inherent risks (Weyandt et al. 2013). The misuse of prescription drugs as nootropics is not new (e.g., Dimond and Brouwers 1976), but the magnitude of this practice is unprecedented—as a result, the topic has gained traction in major popular news outlet, including The New York Times, The Guardian, Time, or The Atlantic.

These consumer trends are based on bold extrapolations from neuroscientific evidence. For example, recent advances have shown that one of the most remarkable features of the brain is that it is plastic—it has the capacity to reorganize itself, and to create new neurons and new synapses across the lifespan. In adulthood, however, neurogenesis and synaptogenesis are often more local and genetically determined than sometimes suggested (Kempermann et al. 1997), and caution is therefore warranted when making inferences from these processes. Even in younger populations, it is not clear yet what cognitive enhancement means (Moreau 2014a), especially regarding the stability of cognitive improvement over time. Nevertheless, the plasticity of the brain remains significant and has the potential to mediate important changes in cognition (Draganski et al. 2004), particularly in children whose nervous system is highly malleable (Kolb and Gibb 2011). Childhood is an ideal period to implement behavioral interventions aimed at cognitive enhancement, because neural plasticity at this age is the norm rather than the exception. This allows larger behaviorally induced cognitive improvement (Green et al. 2012; Steiner et al. 2014), and ultimately the identification and remediation of limitations before they spark off more sizeable difficulties (Franceschini et al. 2013).

To date, one of the most effective way to trigger neurogenesis appears to be physical exercise (van Praag et al. 1999). Importantly, physical exercise is noninvasive and includes numerous beneficial by-products, such as general health improvement and psychological benefits (Paluska and Schwenk 2000). Evidence suggests that aerobic exercise—that is, exercise sustained at a moderate pace for a minimum of 20 consecutive minutes—is the most effective in triggering the release of brain-derived neurotrophic factor (BDNF; Erickson et al. 2011) and in enhancing cognition (Colcombe and Kramer 2003; Hillman et al. 2008), although some studies indicate that other forms of exercise can be as effective (e.g., Liu-Ambrose et al. 2012). The role of BDNF in brain function is wide-ranging, from the formation and maturation of spines and synapses to synaptic restoration, neurogenesis, stem cell and neuronal survival, resistance to brain insult, prevention of neuron degeneration, and general neuroprotection (Egan et al. 2003). Based on these known functions, it has been proposed that increases in BDNF concentration could lead to better cognitive function in normal individuals, and several benefits have been reported in the cognitively impaired (Tapia-Arancibia et al. 2008). However, it is important to note that if newly formed neurons are not integrated within existing neural networks, they typically die within a couple of weeks (Curlik and Shors 2013).

Interestingly, one of the most effective ways to integrate these new neurons within the existing network—and therefore to maximize their chance of survival—is to challenge the brain and force neural adaptation (Shors et al. 2012). Learning a new skill and acquiring new knowledge appear to be especially promising in this regard (Gould et al. 1999).

Based on the idea that brain function greatly benefits from physical exercise and that challenging cognitive stimulations ensure these benefits are maintained over time, researchers have proposed that coupling physical and cognitive demands could be especially interesting when targeting cognitive enhancement (e.g., Curlik and Shors 2013; Moreau and Conway 2013; Tomporowski et al. 2011). In training programs, however, both demands have often been addressed separately, in sequential combinations rather than integrated approaches. At the core of this preference is perhaps the long-standing belief that physical activity cannot adequately incorporate challenging cognitive components, at least not in the sense of most cognitive training programs. In my view, this is a mistake and there are several reasons why it might be pertinent to blend both components within single approaches (Moreau and Conway 2014).

First, and by far the most important for this line of research to impact people's lives and habits meaningfully, a blended approach is time-efficient. Children's time, in and out of school, is limited. For many, an additional hour of brain training a day is thus not reasonable—children still need to do their homework, engage in physical activity, sometimes take music lessons, and take part in numerous other childhood-related activities. Economists speak of opportunity cost to describe the true cost of an activity—in this context, what could a child be doing instead of engaging in cognitive training? Based on this idea, the traditional computerized approach of cognitive training needs to be superior to other effective means of cognitive enhancement, such as physical exercise, because potential gains are often narrow and restricted to trained cognitive abilities. A blended approach elegantly circumvents this problem, bringing together the best of both worlds—thinking while moving, to induce wide-ranging and meaningful improvement.

Second, blending physical and cognitive demands offers an interesting physiological challenge. As different organs in the body compete for resources (e.g., blood supply, nutrients, etc.), the brain is forced to work more efficiently (Gómez-Pinilla 2008), processing information better and faster with less fuel. We have all noticed at times that thinking about elaborate ideas comes relatively easily on a treadmill set at a slow pace, yet any significant increase in speed makes otherwise simple cognitive tasks extremely difficult. This impairment is short-lived—revert back to a slower workout pace and ideas and thoughts begin to flow freely again. Once physical exercise stops, muscle tissue requires less energy, allowing the brain to reclaim its position as the most power-hungry organ of the body (Tomasi et al. 2013). What it means for cognitive interventions is that difficulty can be increased by adjusting the pace of a workout, while holding task demands constant. This allows an additional degree of freedom in the design of adaptive training regimen, and forces the brain to do more with less. Likewise, a drive toward efficiency is often what happens naturally in the acquisition of a new skill—over time, one learns to perform the same skill better while recruiting less cortical structures (Wiesmann and Ishai 2011).

Third, children have a physiological need to burn energy and move around (e.g., Goran and Treuth 2001). This is especially true of children with ADHD who lack the ability to adequately control their impulses (Archer and Kostrzewa 2012), but it can be generalized to childhood as a whole. Inhibiting this behavior is difficult, requires sustained cognitive control, and taps into cortical areas that are the last to mature in late teen years (Bunge et al. 2002). Recent evidence suggests that motor activity may in some instances be a necessary compensatory mechanism that facilitates cognitive functioning, as demonstrated by greater performance on working memory tasks in ADHD individuals—but not typical children—exhibiting spontaneous motor behavior (Sarver et al. 2015). Targeting cognitive enhancement with school-like tasks or computerized means alone is therefore not only difficult, but also profoundly counterproductive. Children are likely not to engage fully with the task at hand, and failures to involve intrinsic motivation at this age can result in poor performance (Deci et al. 1999) or in noncooperative behaviors and dropouts (Vallerand et al. 1997). Arguably, this is even more problematic with children who have learning difficulties—a blend of physical and cognitive components can in this case be particularly suitable and help preserve motivation and engagement, especially since a specific learning disorder rarely impairs all cognitive functions targeted by remediation interventions. If limited verbal abilities are typically detrimental to performance in a given individual, perhaps motor components are not—every child gets to experience areas of ease and difficulties, and all have a chance to shine while being reminded of the value of committed work.

Besides its theoretical support, the combination of physical and cognitive demands into complex motor activities has also been tested empirically, with encouraging results. In a recent study, we assessed the effectiveness of this type of intervention in healthy adults (Moreau et al. 2015). Training was based on the rationale that cognitive improvements, although often substantial following aerobic exercise (Hillman et al. 2008), can be maximized with the addition of challenging cognitive components (Moreau and Conway 2014). Participants were thus presented with perceptive, motor, and cognitive problems in a movement-based framework, while sustaining moderate physical workout. For example, an ad hoc situation was intended to mirror typical working memory tasks, with the replacement of visuospatial or verbal items with motor content, to be executed and recalled when prompted. Difficulty was increased by varying the length of the motor sequence, or by promoting lateral inversions. This adaptive component of the design served a dual-purpose: it ensured participants were presented with challenging material at all times and preserved motivation throughout the program.

Our findings showed that designed sport, an activity specifically tailored to tax working memory and spatial ability by incorporating complex motor coordination in three-dimensional space, outperformed interventions solely focused on either physical or cognitive demands on measures of working memory capacity, spatial ability, and biomarkers of general health, such as resting heart rate and blood pressure (Moreau et al. 2015). This is particularly promising because the cognitive abilities designed sport targeted are critical in many activities—working memory capacity is thought to be a central component of cognition and correlates highly with fluid intelligence (Engle et al. 1999), whereas spatial ability is a significant predictor of success in many academic and professional domains (Hegarty and Waller 2005). Moreover, physiological improvements throughout the program were not trivial and reflect meaningful enhancement that can have a long-term impact on individuals' health (Penedo and Dahn 2005). This approach is still in its infancy, but there is growing evidence that it is also well suited to children in school settings (Tomporowski et al. 2008). For example, independent studies have shown that activities combining executive functioning with physical demands, such as martial arts, might be particularly beneficial to child development (Diamond and Lee 2011). Future work in this area will allow the identification of specific components that are absolutely necessary in a training regimen, and those that should be tailored to each individual (Moreau 2014b).

The fact that optimal interventions ought to combine components does not mean, however, that these should not be evaluated in isolation. Isolating components to extract their respective influence is at the core of the scientific method, and the knowledge that can be gained from this experimental process is critical to inform subsequent integrated programs. For example, it is possible that physical exercise induces benefits only if coupled with training on core cognitive abilities (e.g., working memory capacity), or that physical and cognitive training effects are cumulative, regardless of timing and training regimen. More subtly, perhaps frequency and duration matter greatly—how often one trains, and for how long, might be critical elements of training programs. These are difficult variables to factor into experiments or meta-analyses, as the variability is tremendous and direct replications are rare, yet they are important research questions that will require additional empirical evidence. The field of cognitive training is still in its infancy, and the consequences of combining interventions have yet to be fully understood, but this is undoubtedly a promising venue for research with direct applications to society.

What does this mean for school curriculums? In general, one needs to be skeptical of quick fixes promising large effects: what is the evidence for the system currently in place, or, conversely, what justifies the change? For example, there have been heated discussions about disappointing grades and overall achievement in some of our schools, which have led to questionable responses including cutting down physical exercise in school curriculums. Such actions are known to be completely counterproductive (Strong et al. 2005), and in fact, more time should be allocated to activities that encourage the development of complex motor behaviors in challenging environments. In this regard, the addition of passive or active motor features (e.g., observation, gestures) within traditional learning situations in the classroom is often beneficial, as it can lead to a better understanding of concepts and content (see for example in this issue Agostinho et al. 2015; Mavilidi et al. 2015; Ruiter et al. 2015; Toumpaniari et al. 2015). The implementation of these features requires sustained efforts on teachers' part, but most would agree that it is extremely rewarding to shift from the traditional focus on quantity of physical activity (Ganley et al. 2011) to a qualitative emphasis on movement-based behaviors. In addition, structured plays that combine cognitive challenges with physical motion should also be encouraged, as they allow creating ecological situations that have the potential to trigger important and transferable cognitive improvement. The specific design of this combination—whether it is martial arts (Diamond and Lee 2011), physical activity games (Tomporowski et al. 2008), exergames (Staiano and Calvert 2011), or designed sport (Moreau et al. 2015)—is to be determined based on the objective of the intervention, the suitability of the approach to the educator or the school, and the infrastructures available.

In closing, complex motor activities that combine cognitive and physical demands provide a promising direction for the field of cognitive training. Beyond the cognitive benefits, they can induce when designed adequately, the physiological and psychological improvements complex motor activities allow present critical advantages over computerized training regimens, favored thus far. Eventually, the goal is to integrate motor activities durably within the community, so that habits formed in schools can lead to long-term changes in fitness and cognitive health.

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