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An ecological approach to cognitive enhancement: Complex motor training

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ABSTRACT

Cognitive training has received a lot of attention recently, yielding findings that can be conflicting and controversial. In this paper, we present a novel approach to cognitive training based on complex motor activities. In a randomized controlled design, participants were assigned to one of three conditions: aerobic exercise, working memory training or designed sport — an intervention specifically tailored to include both physical and cognitive demands. After training for eight weeks, the designed sport group showed the largest gains in all cognitive measures, illustrating the efficacy of complex motor activities to enhance cognition. Designed sport training also revealed impressive health benefits, namely decreased heart rate and blood pressure. In this period of skepticism over the efficacy of computerized cognitive training, we discuss the potential of ecological interventions targeting both cognition and physical fitness, and propose some possible applications.

1. Introduction

Can cognition be enhanced via training? Given the relationship between one's cognitive capabilities and numerous factors such as educational and professional achievement (Deary, Strand, Smith, & Fernandes, 2007), socioeconomic status and stress levels (Evans & Schamberg, 2009), and happiness (Pe, Koval, & Kuppens, 2013), the idea that cognitive performance can be improved is extremely appealing. Among other incentives, the potential applications have led researchers to explore the issue intensely in recent years. The resulting body of work includes disparate results and disparate interpretations of the same results that range from optimistic to skeptical (for reviews, see Hillman, Erickson, & Kramer, 2008; Moreau & Conway, 2013; Morrison & Chein, 2011; Rabipour & Raz, 2012; Shipstead, Redick, & Engle, 2012). Here we adopt a new perspective on training and propose a novel paradigm in which both cognitive training and physical fitness are combined into an ecologically valid regimen of complex motor training, which we refer to as designed sport. We compare this novel training with training regimes that primarily tax either cognitive (computerized working memory training) or physical resources (aerobic training) in order to test whether a combined approach can significantly bolster the effects of extant training regimes.

1.1. The cognitive training paradox

Performance enhancement following practice of a particular task is an extremely robust finding in psychology (see for example Schmidt, 1982, for a review in the motor learning domain). The flip side to this well-established finding is that such improvements are often task-specific and therefore rarely transfer to other tasks. A compelling example of task-specific improvement comes from the study of chess grandmasters. In a seminal experiment, Chase and Simon (1973) showed that masters could recall accurately more piece locations on a chessboard than novices in an actual chess game, but this effect disappeared when pieces were placed randomly on the board. Thus, memory enhancement associated with chess expertise is specific to chess patterns and does not transfer to random configurations. Similar effects have been observed among experts in a multitude of activities, and the specificity of training improvements is largely supported in expertise research (see Ericsson, 2006; Ericsson & Charness, 1994 for reviews of expertise-specific improvements).

In 2008, Jaeggi and colleagues questioned the long-standing view of specific improvements and fixed cognitive abilities in adulthood (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). In an influential study, they

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reported improvement in fluid intelligence following working memory training, in line with previous work in clinical populations (Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005). This finding has been replicated since (Jaeggi et al., 2010), and further evidence for transfer from computerized working memory training paradigms to other cognitive abilities has been established by independent research groups (Chein & Morrison, 2010; Jaušovec & Jaušovec, 2012; Perrig, Hollenstein, & Oelhafen, 2009; although see Chooi & Thompson, 2012, Harrison et al., 2013 and Redick et al., 2013, for failures to replicate).

Neuroimaging evidence has also been presented to illustrate the efficacy of working memory training. For example, Olesen et al. (2003) reported increased activity in the middle frontal gyrus and the superior and inferior parietal cortices after five weeks of working memory training, a finding corroborated by a single-subject analysis (Westerberg & Klingberg, 2007), and Hempel and colleagues found increased cortical activation in the right inferior frontal gyrus and the right intraparietal sulcus when performing a spatial working memory task after two weeks of training, but decreased activation after four weeks of training, revealing an inverse quadratic function (Hempel et al., 2004).

This line of research has brought excitement but also skepticism in the field (for recent meta-analyses, see Au et al., 2014; Karbach & Verhaeghen, 2014; Melby-Lervåg & Hulme, 2013). Why would working memory training engender general cognitive improvements where other interventional approaches have systematically failed? The rationale underlying working memory training is perhaps best explained with an analogy. In the sports domain, aerobic conditioning is a prerequisite for performance in many activities. Preseason conditioning often includes an aerobic component to allow building a strong aerobic base necessary to subsequent activity-specific workouts. Aerobic conditioning is only one of many factors that can influence performance, yet because of its central role in numerous physical activities, improvements in aerobic conditioning will often allow general improvements. Similarly, working memory capacity, the maximum amount of information an individual can maintain in working memory, can be thought as the base of many cognitive operations, an idea supported by the relationship between working memory capacity and performance in many cognitive tasks (e.g. Kane et al., 2004). Drawing on this evidence, proponents of working memory training assert that increases in working memory capacity can improve performance in diverse cognitive tasks. However, a strong correlation between two constructs does not guarantee that training one will produce improvements in the other (Moreau & Conway, 2014; Shipstead et al., 2012), as training might tap unshared components. Accordingly, some researchers remain reserved about the potential of working memory training to improve general cognition (Chooi & Thompson, 2012; Owen et al., 2010; Redick et al., 2013; Shipstead et al., 2012), while others have emphasized the need for more research before strong claims can be established (Conway & Getz, 2010; Moody, 2009; Morrison & Chein, 2011; Sternberg, 2008).

1.2. The potential of complex motor activities

There seems to be a contradiction between training on restricted monotonous tasks and expecting wide and generalized changes in cognition (e.g. McDaniel & Bugg, 2012). Given this possible limitation, interventions based on rich and more diverse training environments appear to be a step in the right direction, with a growing amount of literature supporting the efficacy of such programs to produce wide cognitive changes (for reviews, see Green & Bavelier, 2008; Moreau & Conway, 2013) along with observable alterations in neural connectivity (Colom et al., 2012; Voss et al., 2012). Following this idea, complex motor activities combining physical and cognitive demands appear to be a promising way to train cognition.

Previous studies have highlighted the potential of complex motor learning to enhance cognitive abilities, such as spatial ability (Jansen, Titze, & Heil, 2009; Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012). Experts in motor activities also excel in a wide range of cognitive tasks in the laboratory, most notably in domains such as perception (Wright, Bishop, Jackson, & Abernethy, 2011), attention (Memmert & Furley, 2007), decision-making (Raab & Johnson, 2007), working memory (Furley & Memmert, 2010; Moreau, 2013b), long-term memory (Dijkstra, MacMahon, & Misirlisoy, 2008) and dual-processing (Moreau, 2012a). This line of work is corroborated by experimental studies of motor experts' performance in spatial and working memory tasks (Moreau, 2013a,b; Moreau, Mansy-Dannay, Clerc, & Guerrien, 2011). Despite these impressive benefits, complex motor activities have been largely ignored as cognitive enhancers. Most research assess differences in performance between levels of expertise, with very few experimental manipulations being conducted longitudinally to determine how changes in motor activities result in different cognitive improvements and therefore how motor activities can be altered to induce greater or personalized improvements.

Complex motor activities are also appealing because they offer possibilities to bridge cognitive training and physical exercise, which impact on cognition is well documented (for reviews, see Colcombe & Kramer, 2003; Hillman et al., 2008). Aerobic exercise triggers wide neurophysiological changes, such as increases in brain vascularization (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990) and brain insult resistance (Stummer, Weber, Tranmer, Baethmann, & Kempski, 1994). In addition, aerobic exercise leads to increases in proteins and neurotransmitters (Mora, Segovia, & del Arco, 2007), therefore triggering neurogenesis (van Praag et al., 2002), neuronal survival (Vaynman, Ying, Yin, & Gomez-Pinilla, 2006), angiogenesis (Black et al., 1990), and overall brain volume enhancement (Colcombe et al., 2006). Despite these impressive changes at the neural level, this type of training has not been combined with high cognitive demands to optimize the effects of training on cognition. Exercise studies generally reduce physical activity to its physiological component, therefore ignoring the potential of complex motor coordination embedded within aerobic exercise sessions.

Addressing this shortcoming in the exercise literature, we have proposed that specifically designed motor activities, which tax working memory and spatial ability by incorporating motion in three-dimensional space, represent an optimal way to induce transfer across tasks, while combining the benefits of traditional cognitive training and physical exercise into a single activity (Moreau & Conway, 2013). Moreover, the emphasis on spatial ability is especially relevant to cognitive training given the underrepresentation of spatial activities in educational curricula (Moreau, 2012b; Newcombe & Frick, 2010).

1.3. Current experiment

The aim of the present study was to assess the potential of a novel cognitive training program based on complex motor skills, which we have labeled designed sport. Designed sport includes spatial ability and working memory demands while concurrently requiring sustained physical activity. Therefore, this regimen offers an integrated approach to cognitive training, bridging psychology and exercise sciences literatures.

In order to assess its validity against current cognitive training paradigms, designed sport was compared with a working memory training regimen. Complex span working memory training was selected as a desirable computerized cognitive training comparison because of prior evidence of a strong relationship between complex span and various other cognitive measures (e.g. Kane et al., 2004) and because of prior demonstrations of the effectiveness of complex span training to enhance performance on untrained measures of working memory and cognitive control (Chein & Morrison, 2010; Harrison et al., 2013). Moreover, complex span training includes two components — spatial and verbal — that have been shown to activate overlapping but also distinct cortical regions (Chein, Moore, & Conway, 2011).