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Exercise mode and executive function in older adults: An ERP study of task-switching

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ABSTRACT

The purpose of this study was to investigate the relationship between exercise mode and executive function and its effect on behavior and neuroelectric activity. Forty-eight older adults were classified into open-skill, closed-skill, and irregular exercise groups based on their experience of exercise participation. Executive function was measured via a task-switching paradigm, in which the behavioral indices and event-related potentials elicited by task-switching were assessed. The results revealed that the exercise groups, regardless of the exercise mode, exhibited faster reaction times in both global and local switches than the irregular exercise group, regardless of the within-task conditions. Similarly, larger P3 amplitudes were observed in both exercise groups compared to the irregular exercise group. Moreover, additional facilitation effects of open-skill exercises on global switch costs were observed, whereas no differences in local switch costs were found among the three groups. The results replicate previous studies that have reported generally improved executive function after participation in exercises; additionally, they extend the current knowledge by indicating that these cognitive improvements in specific aspects of executive function could also be obtained from open-skill exercises.

1. Introduction

The beneficial effect of physical activity on cognition in older adults is well documented. With the growth of large-scale epidemiological research, several meta-analyses have reported that participation in physical activities may ameliorate the loss of cognitive functions or prevent cognitive aging; positive changes of small to large magnitudes resulting from physical activity have been identified (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003; Smith et al., 2010; Sofi et al., 2011).

The effect of physical activity on cognition may be selectively sensitive. Compared to cognition involving speed, spatial and controlled features, cognition that engages executive control involves gains resulting predominantly from the beneficial effects of physical activity in older adults (Colcombe & Kramer, 2003). Notably, whereas disproportional effects have been consistently observed in a number of studies (Hillman et al., 2006; Pontifex et al., 2011; Wu et al., 2011), a meta-analysis conducted by Smith et al. (2010) indicates that similar modest improvements are observed in executive function, memory, attention, and processing speed. Therefore, there are conflicting views regarding large effects of physical activity on executive function. These differences most likely result from executive function itself. Although executive function is typically recognized as a higher-order cognitive ability that monitors and manages multiple basic cognitive functions for purposeful behaviors (Alvarez & Emory, 2006; Best, Miller, & Jones, 2009), it comprises distinguishable subcomponents. For example, according to different researchers' perspectives, executive function may include shifting, updating, inhibition (Miyake et al., 2000), set shifting, attentional control, planning, and verbal fluency (Jurado & Rosselli, 2007). Considering the multifaceted nature of executive function, Etnier and Chang (2009) postulated that the effect of physical activity on executive function subcomponents could be distinguished and identified by the relationships of these subcomponents with physical activity; therefore, these authors encouraged examination of the specific aspects of executive function.

Switching is one of the main aspects of executive function and is particularly emphasized in the present study. Switching from a single rule to an alternative one to address constantly changing

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demands is common in goal-directed behavior, and task-switching is a major method used to investigate dynamic executive functions in experimental studies (Kiesel et al., 2010; Monsell, 2003; Rogers & Monsell, 1995). The earliest task-switching paradigm using the "list procedure" was developed by Jersild (1927). Switching ability, known as *global switch cost* or *mixing cost*, was measured as the reaction time difference between a homogeneous/pure block (e.g., AAAAAA or BBBBBB) and heterogeneous/mixed block (e.g., ABABAB). However, compared to homogeneous blocks, responding to heterogeneous blocks engages greater switching ability and working memory load, thus confounding the global switch cost. The alternative runs paradigm (Rogers & Monsell, 1995), which describes predicable order shifts between trials within a heterogeneous block (e.g., AABBAABB), was developed to measure the actual switching ability of the *local switch cost* or *switch cost*. Local switch cost refers to reaction time differences between non-switching (e.g., AA or BB) and switching trials (e.g., AB or BA). Whereas the global and local switch costs reflect distinct constructs (Kray & Lindenberger, 2000), increased switch costs are generally observed in aged adults, which implies that older adults must engage in more task-set reconfigurations or switch recourse demands during task-switching tests (Themanson, Hillman, & Curtin, 2006; Wasylyshyn, Verhaeghen, & Sliwinski, 2011).

In a randomized controlled trial (RCT), Kramer et al. (1999) investigated the effect of physical activity on switching in older adults. These authors found that older adults who participated in a walking program for 6 months demonstrated better performances in the task-switching switch condition than those in the toning control group. No difference was observed between these groups in the non-switching condition. These results suggest that only aerobic exercise facilitates task-switching performance involved in executive control processes. Similarly, in elderly individuals, moderate-intensity physical activity is negatively associated with intra-individual variation in reaction time in task-switching (Kimura, Yasunaga, & Wang, 2012). It was therefore suggested that physical activity facilitates behavioral switching aspects of executive function.

An alternative research perspective has involved examining the relationship between physical activity and task-switching at the neuroelectric level using event-related potentials (ERPs) (Hillman, Kramer, Belopolsky, & Smith, 2006; Kamijo & Takeda, 2010; Scisco, Leynes, & Kang, 2008; Themanson et al., 2006). An ERP is a time-locked brain wave that is elicited by specific stimuli, events, or responses (Fabiani, Gratton, & Federmeier, 2009). ERP offers high temporal resolution and thus could provide a precise evaluation of implicit cognitive processing. For example, one dominant ERP component, P3, reflects allocation of attentional resources and stimulus classification efficiency based on its induced amplitude and latency, respectively (Polich, 2007). Notably, although prior ERP studies have generally demonstrated positive effects of physical activity on task-switching in behavior and neuroelectric activity, the results were inconsistent. For example, older adults with high levels of physical activity demonstrated better performance in global and local switches and higher P3 amplitudes than older adults with low levels of physical activity (Hillman, Kramer, et al., 2006). Additionally, better performance has been demonstrated only in global switch cost, not in local switch cost, when comparing active older adults to their sedentary counterparts (Themanson et al., 2006). In contrast, no fitness effects or P3 influences were observed in comparisons of performance in switching and non-switching conditions in younger adults; switch costs were not assessed (Scisco et al., 2008). Obviously, these conflicting results introduce uncertainty in the relationship between physical activity and task-switching. Because these studies used different methodological task-switching indices, leading to results that cannot be compared between studies, the present study attempts to clarify whether older adults' participation in physical activity influences switching by comprehensively examining task-switching indices, namely global switching, global switch cost, local switching, and local switch cost.

Another factor that may contribute to exercise's effect on cognition is exercise mode. Although few recent studies have emphasized the effect of resistance exercises (Chang, Pan, Chen, Tsai, & Huang, 2012; Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012) or alterative exercise modes (Chang, Nien, Tsai, & Etnier, 2010) on cognition, the majority of exercise-cognition research focuses on aerobic exercise. According to Schmidt and Wrisberg (2008), motor skills involved in specific exercises can be categorized into open-skill (e.g., table tennis, tennis, and badminton) and closed-skill (e.g., jogging and swimming) based on the consistency and predictability of the performing environment. Compared to closed-skill exercises, open-skill exercises require constant behavioral adaptation in response to unpredictable stimuli, and more cognitive resources must be invested to increase the efficiency of decision-making processes.

Increased cognitive demands within exercise may facilitate cognition (Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). For example, using animal models, Fabel et al. (2009) indicated that wheel-running and environmental enrichment conditions stimulate adult hippocampal neurogenesis in mice. This finding was correlated with improved cognition. When wheel-running and environmental enrichment conditions were combined, the mice showed a 30% increase in precursor cell proliferation and neurogenesis relative to either condition alone. Similar results have been recently found in humans (Taddei, Bultrini, Spinelli, & Di Russo, 2012; Yan, 2011). In a study comparing experienced fencers and non-fencers, fencing experience and fitness levels enhanced inhibitory control (Yan, 2011). Taddei et al. (2012) further found facilitation in experienced fencers in both simple and discriminative reaction time tasks, regardless of whether the fencer was young or middle-aged. In addition, although middle-aged adults exhibited longer P3 latencies than younger adults, middle-aged adults with professional fencing experience demonstrated shorter P3 latencies and larger P3 amplitudes, which suggests that involvement in open-skill exercises protects against aged-related cognitive decline. However, it should be noted that these studies emphasized fencing as an open-skill exercise and did not include a closed-skill exercise for comparison. To date, no studies have examined the switching aspect of executive function. Therefore, whether open-skill exercises provide equivalent or additional stimulation in specific types of executive function relative to aerobic exercise remains unclear and requires further investigation (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011).

This study attempted to the increase knowledge and understanding of the effect of physical activity on cognition by examining exercise mode and specific types of executive function using both behavioral and neuroelectric approaches. Specifically, the purpose of the study was to determine the effect of open-skill, closed-skill, and irregular exercise on the switching aspect of executive function using a task-switching paradigm and its induced ERP indices. The neuroelectric indices of task-switching are comprehensively presented. We hypothesized that older adults participating in regular exercise would exhibit better switch-related performance than those with irregular exercise experience, regardless of behavioral and neuroelectric indices. Moreover, we predicted that older adults with experience in open-skill exercises would experience more beneficial effects than those with closed-skill experience.