Psychology of Sport and Exercise 15 (2014) 205–211

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

journal homepage: www.elsevier.com/locate/psychsport

Type of physical exercise and inhibitory function in older adults: An event-related potential study

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ARTICLE INFO

Article history:
Received 21 April 2013
Received in revised form
14 November 2013
Accepted 14 November 2013
Available online 25 November 2013

Keywords:
Executive function
Physical activity
Aging
Interference control

ABSTRACT

Objectives: The present study was to examine the relationship between exercise type and inhibitory function in older adults using neuroelectric indices.
Design: A cross-sectional design was employed in the present study.
Method: Sixty adults ($M = 69.42$ years) were categorized into open-skill, closed-skill, and irregular exercise groups according to their history of exercise participation. The participants conducted a flanker task while their behavioral performance and event-related brain potentials were assessed.
Results: The results indicated that regular exercisers, regardless of exercise type, exhibited a faster reaction time across conditions of the flanker task compared to irregular exercisers. For the P300 amplitude of the open-skill exerciser group, the peak amplitude was larger at the vertex site compared to the frontal site, whereas no site differences were observed in the closed-skill and irregular exerciser groups.
Conclusions: These findings extend current knowledge by suggesting that, for older adults, participation in physical exercise involving increased cognitive demand is associated with better neural efficiency in resource allocation for tasks that require interference control.

Introduction

Previous studies have consistently revealed linear age-related decrements in cognitive functions during activities that involve attention, cognition, and memory, especially those requiring extensive amounts of executive function (Kramer, Hahn, & Gopher, 1999; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000). For example, by examining stimulus-locked event-related potentials (ERPs), previous study has reported that older adults demonstrate increased information processing speeds compared to younger adults while conducting cognitive tasks (Friedman, Nessler, Johnson, Ritter, & Bersick, 2008), which suggests that executive control functioning substantially declines with increasing age. Executive function refers to a subset of goal-directed processes that include planning, scheduling, working memory, interference control, and task coordination (Chan, Shum, Toulopoulou, & Chen, 2008). Because executive dysfunction has been found to be associated with functional impairment in elderly residents living in assisted-living facilities (Burdick et al., 2005), follow-up research is needed to define effective interventions that target the maintenance or even improvement of executive functioning among older adults.

A considerable amount of research has indicated that aerobic fitness or participation in physical activity is related to reducing or even reversing age-related decrements in executive function (Colcombe & Kramer, 2003; Erickson et al., 2009; Etnier, Nowell, Landers, & Sibley, 2006; Hillman, Erickson, & Kramer, 2008). However, based on the conclusions of a meta-analysis, Smith et al. (2010) demonstrated an incongruous view of the effects of physical activity on executive functioning. These authors argued that aerobic exercise training contributed to only modest improvements in executive function as well as attention, processing speed, and memory; in other words, increases in cardiovascular fitness did not necessarily benefit executive function. This contradiction is likely due to other potential factors that may moderate the association between physical activity and human executive function.

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http://dx.doi.org/10.1016/j.psychsport.2013.11.005

Specifically, other forms of physical activity that do not exclusively emphasize aerobic fitness might affect the relationship between physical activity and cognitive function. For example, after conducting a meta-analysis, Colcombe and Kramer (2003) concluded that aerobic exercise produced a moderately beneficial effect ($EF = 0.41$) on cognitive function in older adults, whereas exercise interventions that combined both cardiovascular and resistance forms generated a superior effect ($EF = 0.59$) on cognitive aging. Additionally, Lam et al. (2009) used a self-reported survey to differentiate the cognitive benefits among older adults who participated in various types of exercise, indicating that elderly subjects who regularly engaged in aerobic types or mind-body types of exercise demonstrated similar cognitive benefits. Furthermore, functional brain imaging data have revealed that physical fitness indexed according to cardiovascular fitness, muscular strength, and motor fitness was differentially associated with cognitive processes among older adults (Voelcker-Rehage, Godde, & Staudinger, 2010). Therefore, in addition to aerobic exercise, whether other forms of exercise can provide equivalent or additional protection against age-related declines in cognitive function, especially executive function, requires further exploration.

Given that a majority of research has focused on the effects of cardiovascular (Erickson et al., 2009; Hillman, Weiss, Hagberg, & Hatfield, 2002) and resistance (Chang, Pan, Chen, Tsai, & Huang, 2012; Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012) exercise modes on cognitive function in the elderly, very little has been done to compare the cognitive benefits (i.e., executive function) between open- and closed-skill types of exercise. The classification of open-skills (e.g., tennis, basketball, badminton) and closed-skills (e.g., swimming, jogging, walking) depends on the predictability of the performing environment (Schmidt & Wrisberg, 2008). Compared to closed skills, open skills require individuals to invest higher cognitive effort in response to immediate external stimuli that arise from an unpredictable environment. Importantly, incorporating increased cognitive demand into physical exercise can provide additional facilitation for cognition in older adults. This notion is supported by previous research in human subjects (Tranter & Koutstaal, 2008), which has indicated that multimodal interventions focusing on participation in activities that are cognitively, physically, and socially demanding may derive more cognitive benefits for older individuals. Additionally, other studies have shown that Tai Chi Chuan could be beneficial to executive function (Matthews & Williams, 2008; Taylor-Piliae et al., 2010) due to its specific exercise modality, which requires participants to concentrate on body postures and movement sequences while exercising physically. Similar results were extended to studies on experienced fencers, reporting that adults with fencing experience demonstrated more rapid simple and discriminative reaction times (RTs) (Taddei, Bultrini, Spinelli, & Di Russo, 2012) as well as better inhibitory control (Chan, Wong, Liu, Yu, & Yan, 2011) than those with no fencing experience. These findings provide further support that participation in open-skill exercise may be helpful for diminishing aged-related cognitive decline. Animal studies have also indicated that increased cognitive, physical, and social enrichment in living environments can stimulate the proliferation of precursor cells and hippocampal neurogenesis and enhance the expression of brain-derived neurotrophic factor (BDNF), which can have diverse functions in brain development and plasticity (Cao et al., 2010; Fabel et al., 2009). Taken together, these previous findings have suggested that a greater amount of cognitive investment in physical exercise can demonstrate more promising benefits to executive function when compared to physical exercise that involves a relatively smaller cognitive requirement. However, it should be noted that the previous studies emphasized fencing as an open-skill exercise and few comparisons of cognitive effect have been directly conducted between the open- and closed-skill types of exercise. Therefore, it is highly useful to examine whether open-skill types of exercise can offer additional cognitive benefits than closed-skill types of exercise.

Because the beneficial effect of physical activity on executive function can be selectively sensitive, the present study focused on inhibition, which is a major component of executive function. According to the inhibitory deficit hypothesis, declines in cognitive function are primarily driven by inefficient inhibitory processing in older adults (Hasher, Lustig, & Zacks, 2007), which reflects an impairment in the ability to suppress task-irrelevant information and focus attention on task-relevant information. The Eriksen flanker task (Eriksen & Eriksen, 1974) along with neuroelectric indices of the P300 component of the ERP have been frequently employed to assess inhibition. It is believed that the responses are slower and less accurate for incongruent stimuli than for congruent stimuli in the flanker task because the incongruent condition requires larger amounts of interference control, resulting from the low compatibility of the flanking stimuli. Additionally, the P300 component is proposed to denote memory storage and serve as a link between stimulus characteristics and attention and is also considered to be an indicator for cognitive brain functions such as attention, memory, and context updating (Bramon et al., 2005). The amplitude of the P300 reflects the allocation of attentional resources during stimulus encoding, while its latency reflects the speed of cognitive processing toward the stimuli. By evaluating cognitive performance in the flanker task, older adults who participated in cardiovascular or coordination training (Voelcker-Rehage, Godde, & Staudinger, 2011) demonstrated better inhibitory functioning, as reflected by faster RTs and higher response accuracy in comparison to their control counterparts. Hillman et al. (2006) also revealed a positive association between physical activity and response accuracy for older adults. Furthermore, based on the P300 indices recorded during the flanker task, physical activity was found to relate to improved inhibitory processing in older adults by increasing the P300 amplitude and decreasing the P300 latency (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004). However, Kamijo et al. (2009) found that the P300 latencies following both light and moderate exercise were shorter compared to the no-exercise baseline condition, although the increased P300 amplitude was not observed after the exercise sessions. Given that behavioral data usually reveal positive effects of physical activity on inhibitory processing, the ERP indices demonstrated inconsistent findings. Because the ERP is characterized by its high temporal resolution, which can provide precise evaluation to reflect implicit cognitive processing, future research should continue to explore the association between physical activity and inhibitory function in older adults using the ERP measurement.

Altogether, the aim of this study was to examine differences in inhibitory function between older adults who engage in different types of exercise using the ERP technique. The current study involved a cross-sectional comparison of physical activity influences on interference control and predicted that older adults who frequently participated in either less predictable open-skill exercise or more predictable closed-skill exercise would exhibit better performance in terms of RT than those with an irregular exercise habit, across the conditions of the flanker task. Furthermore, older adults conducting open-skill exercise were predicted to demonstrate better task performance on RT than those conducting closed-skill exercise. We also hypothesized that older adults who frequently participated in physical exercise would exhibit a larger P300 amplitude for stimulus-locked ERPs, along with a faster cognitive processing speed (P300 latency), compared to those who were irregular exercisers. Additionally, older adults conducting