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Executive functions improvement following a 5-month aquaerobics program in older adults: Role of cardiac vagal control in inhibition performance

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ABSTRACT

The aims of this study were to examine the effects of aerobic exercise on measures of executive performance and their relationships with changes in cardiorespiratory fitness, cardiac vagal control (heart rate variability) and psychological variables. Thirty-six sedentary seniors aged 60–75 years were randomly assigned to a swimming and aquaerobics program or a stretching program two times a week for 21 weeks. Executive functions (inhibition, updating of working memory and cognitive flexibility) and cardiorespiratory fitness (estimated VO_2max) were assessed at the start, after 10 weeks of program and at the end of the program. Resting HRV and measures of psychological outcomes (depression, self-efficacy, decisional balance) were obtained at the start and at the end of the program. Participants of both groups significantly improved their VO_2max level, their psychological state and their performance for the 2-back task. Only the participants in the aquaerobics group significantly improved their vagally-mediated HRV and their performance for the Stroop test and the verbal running-span test at the end of the program. Only improvements in cardiac vagal control and in inhibition were shown to be functionally related. These results are discussed in line with the model of neurovisceral integration.

1. Introduction

Cerebral and cognitive declines as a function of normal aging represent one of the most prominent causes of autonomy loss in the aging population. However, growing evidence shows that aerobic physical exercise, which improves cardiorespiratory fitness, might be effective in slowing the rate or even reversing these cerebral and cognitive declines associated with aging. Numerous interventional studies have examined the efficacy of different physical exercise training programs using various designs and durations on improving cognitive performance. However, recent meta-analytic studies have pointed out several discrepancies and inconsistencies between the studies and conclusions (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Kelly et al., 2014; Smith et al., 2010). Particularly, the questions on whether aerobic exercise is beneficial to all or some particular cognitive functions, the time course of the potential effects and the key mechanisms responsible for the potential benefits were pointed out, and are investigated in the present study.

First, it is not clear whether aerobic exercise has a global positive effect on cognitive performance or a more selective effect on particular cognitive functions. Among them, executive functions (EFs) have received particular attention in recent years. Executive functions refer to a set of higher-order cognitive processes of control and coordination allowing behavioral adaptation to complex or novel situations. They are critical for the activities of daily living and autonomy, but are one of the most altered cognitive functions due to normal aging (Albinet, Boucard, Bouquet, & Audiffren, 2012; West, 1996). Although converging evidence from narrative and meta-analytic reviews (Colcombe and Kramer, 2003; Hall, Smith, & Keele, 2001) as well as experimental studies (Abou-Dest, Albinet, Boucard, & Audiffren, 2012; Albinet, Boucard, Bouquet, & Audiffren, 2010; Kramer et al., 1999; Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008) suggest that prefrontal-related tasks involving executive control may be strongly and selectively improved by aerobic exercise, inconsistent findings have also been reported. For example, three different recent meta-analyses failed to demonstrate that aerobic exercise was more beneficial to EFs than to other

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cognitive functions, such as processing speed or memory (Smith et al., 2010), and some even failed to show any consistent benefit (Angevaren et al., 2008; Kelly et al., 2014).

It is difficult to draw a final conclusion on these results because of the heterogeneity in the tasks used across studies to evaluate executive control, often without a clear theoretical framework and justification of the used tasks, and because of the fractionated nature of the EF construct. As mentioned, EFs are not a unitary construct but may be fractionated in at least three separate, yet correlated, components: inhibition of thoughts, impulses and actions, updating of working memory (WM) and cognitive flexibility (Albinet et al., 2012; Miyake et al., 2000). Because of the problem of task impurity, one single task is unable to adequately assess one isolated EF and this problem may have contributed to the discrepancy in previous experimental results (Abou-Dest et al., 2012; Albinet et al., 2012; Boucard et al., 2012; Etnier and Chang, 2009). Recently, works from our team have proposed and validated the interest of using a multi-task approach to examine the relationship between regular exercise or cardiorespiratory fitness and executive performance (Abou-Dest et al., 2012; Boucard et al., 2012). These studies showed that maintaining good cardiorespiratory fitness through regular exercise is associated with some preservation of executive performance, particularly behavioral inhibition, but that some experimental tasks appear to be more sensitive to the exercise effects than others. However, the cross-sectional nature of these studies precludes inference about the cause–effect relationship between aerobic exercise or cardiorespiratory fitness and executive performance. One objective of the present study was to further validate the interest of this multi-task approach in a randomized–controlled trial, by examining the causality between physical activity (PA) and improved executive performance in older adults.

Second, although the minimal length of aerobic exercise training for expecting cardiovascular benefits is well documented (Chodzko-Zajko et al., 2009), the minimal or optimal program duration for observing cognitive benefits has received very little attention (Kelly et al., 2014). To our knowledge, no study has yet specifically examined this question. Only Colcombe and Kramer (2003) in their meta-analysis of 18 randomized-controlled trials (RCT's) reported some intriguing conclusions. They showed that overall, the programs lasting more than six months lead to the better results. Surprisingly, they also reported that short programs (1–3 months) lead to significantly larger cognitive improvements than medium programs (4–6 months). These authors gave no explanation to this paradoxical result, but one can hypothesize that some short-term learning phenomena (test–retest improvement) and/or motivation can in part be involved in these improvements in cognitive performance. Moreover, we have yet no clear idea on whether the time scale is the same for physiological and cognitive effects following aerobic exercise training. In order to examine more closely the dynamic of the effects of two PA programs on cognitive and physiological outcomes in the same study, we performed an intermediate evaluation after 10 weeks of training and a final evaluation at the end of the program at 21 weeks.

Finally, the fundamental mechanisms responsible for the positive effects of aerobic exercise on cognitive performance are not well clarified and still poorly understood. Broadly speaking, the proposed mechanisms that may involve cognitive benefits belong to two main areas: neurobiological mechanisms on one hand and psychological mechanisms on the other hand (Audiffren and André, 2015; Audiffren, André, & Albinet, 2011). An increasing amount of literature has documented the neurobiological benefits of aerobic exercise and has shown that the exercise-induced release of neurotrophic factors that facilitate neurogenesis, angiogenesis, and neurovasculature may play an important role in brain plasticity and cognition (Cotman, Berchtold, & Christie, 2007; Hillman, Erickson, & Kramer, 2008; Voelcker-Rehage and Niemann, 2013). These mechanisms are thought to strongly rely on the cardiovascular benefits due to chronic aerobic exercise (Albinet, Mandrick, Bernard, Perrey, & Blain, 2014). However, at a behavioral level, the direct link between cardiorespiratory fitness level, assessed by maximal oxygen uptake (VO_2max), and cognitive performance in older adults has not been consistently demonstrated (Abou-Dest et al., 2012; Etnier, Nowell, Landers, & Sibley, 2006; Smiley-Oyen et al., 2008), particularly in interventional studies. It may be that other cardiovascular markers, such as heart rate variability (HRV) and cardiac vagal control, could provide better indices of improvements in executive performance and prefrontal cortex activity, than only cardiorespiratory fitness improvements as assessed by VO_2max. In this line, Thayer and co-workers have developed a model of neurovisceral integration linking the heart–brain connections and building the foundations for a unified structural and functional network linking HRV, prefrontal neural structures, and psychological processes such as executive functioning (Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Thayer and Lane, 2009). Based on pharmacological, neuroimaging, and behavioral evidences, this model describes the pathways linking the prefrontal cortex to autonomic motor circuits responsible for both the sympatho-excitatory and parasympatho-inhibitory effects on the heart. This modulation of cardiac activity by the prefrontal cortex is mediated by vagal control and research has shown that this control of the cardiovascular system is related to efficient cognitive functioning and is correlated with activity of the prefrontal cortex (Gianaros, Van Der Veen, & Jennings, 2004; Hansen, Johnsen, & Thayer, 2003). Of particular importance in the context of the present study, it was shown that HRV is reduced in older adults (Kim et al., 2006) and that prefrontal control of HRV is impaired as we age (Thayer, Sollers et al., 2009). However, HRV can be increased by aerobic exercise training (Albinet et al., 2010; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004). Nevertheless, to date, no study has yet simultaneously examined the effects of two different exercise training programs on VO_2max level, HRV parameters and executive performance in older adults.

Psychological improvements have been also proposed as potential mediators of the exercise–cognition relationship. It has been shown that physical exercise training can improve psychological outcomes and well-being such as quality of life and self-efficacy, as well as depression (Bridle, Spanjers, Patel, Atherton, & Lamb, 2012; Dionigi, 2007; Mullen, McAuley, Satariano, Kealey, & Prohaska, 2012). It is conceivable that these psychological improvements may increase the exercisers' confidence in their abilities, allowing them to invest more mental effort during cognitive challenging tasks, and thus improving their executive performance. However, this hypothesis has never been examined in relation to executive functions and cardiovascular improvements in an interventional study involving older adults. Therefore, in the present study, participants were evaluated for depression, self-efficacy and decisional balance in order to determine the contribution of the effects of psychological variables in the improvement of cognitive performance induced by physical activity training.

To sum-up, the aims of this study were to examine in a same sample of older adults, the effects of an aquatic aerobic exercise training program on measures of executive performance and their potential relationships with changes in cardiorespiratory fitness (VO_2max), cardiac vagal control (HRV) and psychological variables. Aquatic activities were chosen because they are one of the most popular and accessible forms of PA and were shown to be related to some preservation of cognitive performance in older adults (Abou-Dest et al., 2012; Hawkins, Kramer, & Capaldi, 1992). We hypothesized that the participants in the aquatic aerobic exercise training program will improve their cardiorespiratory fitness, their cardiac vagal control and their performance on executive control