Brain and Cognition 125 (2018) 127–134

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Higher cardiovascular fitness level is associated to better cognitive dual-task performance in Master Athletes: Mediation by cardiac autonomic control

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ARTICLE INFO

Keywords:
Executive performance
Dual-task
Fitness level
Parasympathetic control
Master Athletes

ABSTRACT

Introduction/Purpose: This study compared cognitive performances and cardiac autonomic measures of higher fit and lower fit middle-aged and older highly active adults. The working hypotheses were that higher fit (master athletes) would show cognitive benefits in executive control conditions due to a high level of fitness compared to lower fit people and that this effect would be mediated by better cardiac autonomic adaptations in athletes.
Methods: We recruited 39 highly active middle aged and older adults from Master Athletes' organizations. All participants performed a Rockport walking test and a computerized dual-task. Cardiac autonomic control was assessed with a measure of heart rate variability. Based on the $\dot{V}O_{2max}$ estimated by the Rockport test, a median split was performed to assess the influence of fitness level on cognitive performance and the link with heart rate variability. Those with the highest fitness level were considered Master Athletes.
Results: Master Athletes showed better dual-task performances than lower fit individuals. A positive relationship between the $\dot{V}O_{2max}$ and dual-task performances was also observed. Master Athletes demonstrated a lower resting HR and higher RR interval than lower fit individuals, and this index was specifically related to the executive conditions of the dual task.
Conclusion: Our results highlight the role of fitness level on executive function in highly active middle aged and older adults and suggest that the better performances observed in highly fit individuals is mediated by cardiac autonomic control.

1. Introduction

Aging is often accompanied by performance declines in multiple cognitive domains. It is generally assumed that process-based or fluid abilities (i.e., reasoning, speed and other basic abilities not dependent on experience) display earlier age-related declines, as opposed to knowledge-based or crystallized abilities (verbal knowledge, language, comprehension), which can be maintained and even improved over the lifespan (Salthouse, 2010) . Among fluid abilities, executive functions (EFs; planning, inhibiting, switching) and attentional control are particularly sensitive to aging (McDowd, Shaw, 2000). Executive control deficits impair the ability to manage several tasks simultaneously (or dual-task), which can have an important impact on everyday functioning since many activities of daily living require managing multiple tasks (e.g., driving, walking and talking). Age-related deterioration of this ability has often been associated with substantial anatomical and physiological changes (Bishop, Lu, & Yankner, 2010), particularly in the frontal areas of the cerebral cortex (Raz, 2000). However, this changes seem to be reduced with regular physical activity (Yuki et al., 2012).

Currently, it is recognized that regular physical activity is "the best medicine" (DeWeerdt, 2011) for maintaining global health. Recent studies have suggested that physical activity may protect against the neurological pathology associated with aging, including Parkinson's and Alzheimer's disease (DeWeerdt, 2011). In addition, in "normal" non-pathological aging, several studies have supported a delay in cognitive decline in physically active individuals (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Intervention studies also tend to support the notion that physical activity not only reduces cognitive decline but can also lead to improved cognition in older

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https://doi.org/10.1016/j.bandc.2018.06.003
Received 22 January 2018; Received in revised form 1 June 2018; Accepted 8 June 2018

adults. These studies suggest that higher order attentional control processes show the greatest improvements from enhanced cardiorespiratory functions induced by aerobic training (Colcombe and Kramer, 2003). The benefit of aerobic training on attentional control was explored in a study by Kramer et al. (1999). The authors observed that in comparison to controls, the participants in the aerobic group showed an improvement on several cognitive tasks (*answer compatibility task, Task switching, Stop signal*), but more so, in tasks that required EF processes. Other research has adopted the dual-task paradigm in order to explore age-related changes in attentional control processes (Fraser and Bherer, 2013) and related improvements after aerobic training (Hawkins, Kramer, & Capaldi, 1992). The dual-task paradigm directly tests the individual's ability to manage multiple tasks simultaneously and indirectly measures various attentional control functions.

These studies suggest that aerobic fitness training is an effective way to enhance cognition in older adults and to selectively improve EF (Colcombe and Kramer, 2003). However, the dose-response relationship between fitness level and cognitive health benefits in older adults is unclear. Generally, the gold standard measure of fitness level is maximal oxygen uptake ($\dot{V}O_{2max}$). To date, the $\dot{V}O_{2max}$ level that induces the greatest improvements in cognition remains unknown. Some studies support a dose-response relationship where higher levels of fitness are accompanied by the greatest improvements in cognitive processing (Vestberg, Gustafson, & Maurex, 2012). In professional athletes it is possible to predict physical performance based on EF scores (Vestberg et al., 2012). However, this dose-response relationship has only been identified in young people and in professional athletes. In older populations, most studies published so far included moderately active healthy individuals or sedentary older adults often with wide range heterogeneity in cognitive and fitness levels. As such, in middle-aged and older adult samples, the benefits of higher physical fitness levels on cognitive performance and more particularly on executive control are lacking. To the best of our knowledge, there is only one study that explored the cognitive performance of Master Athletes. Authors reported a better cardiorespiratory response during exercise than sedentary counterparts, together with a better performance in letter and category fluency neuropsychological tests (Tseng et al., 2013). While these results suggest both cognitive and physical advantages for Master Athletes, the cognitive performance findings need to be interpreted with caution as certain sample of participants had low scores on the Montreal Cognitive Assessment (MoCA) that indicated mild cognitive impairment.

In terms of cognitive advantages, a growing body of literature has focused on understanding how physical training enhances cognitive performance (Bherer, Erickson, & Liu-Ambrose, 2013). The preliminary research on this topic has fostered the development of theoretical models that assess and attempt to identify the neurophysiological pathways by which physical training enhances cognitive function. Several anatomical and neurophysiological parameters seem to be associated with improvement in EF in healthy fit subjects (Bherer et al., 2013). One model that attempts to explain the relationship between physiology and cognitive function is the Neurovisceral Integration model (Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012, 2009), which proposes neuroanatomical connections between the central and the autonomic nervous system. According to this model, there is an interaction between parasympathetic cardiac autonomic regulation and EF processes that are controlled by the prefrontal cortex (PFC). This network can be considered an internal regulation system through which the brain controls visceromotor, neuroendrocrine and behavioral responses to environmental challenges. Thayer et al. (2012, 2009) proposed heart rate measures as an index of central autonomous network (CAN) activity and executive functioning. According to the model of Rosenblueh and Simeone (Rosenblueth, 1934), resting heart rate (HR) and its modulation are under the neural influences of parasympathetic and sympathetic effects. Heart rate variably (HRV) is also a non-invasive method to determine the CAN activity and the autonomic control of the cardiovascular system. In support of this proposal, a recent meta-analysis (Thayer et al., 2012) and several studies (Hansen, Johnsen, & Thayer, 2003; Kimhy et al., 2013), have reported that individuals who performed better in cognitive tasks often demonstrated a greater cardiac parasympathetic control than those with poorer cognitive performance. The age-related decline in cognitive performance has also been associated to lower HRV (Frewen et al., 2013). Altogether, these results suggest a close relationship between the parasympathetic control of the cardiovascular system and executive performance (Duschek, Muckenthaler, & Werner, 2009; Hansen et al., 2003; Kimhy et al., 2013; Thayer, Hansen, Saus-Rose, & Johnsen, 2009). In the domain of attentional control, several previous studies have also reported a positive relationship between parasympathetic cardiac control and attentional control (Duschek et al., 2009; Porges, 1992). Porges (1992) proposed a model on the link between cardiac parasympathetic activity and interindividual differences in attention and postulated that higher cardiac parasympathetic control is associated with better attentional capacity.

Taken together, evidence suggests a positive dose-response relationship between high levels of fitness and high levels of executive performance that is related to cardiac parasympathetic control. However, no study has looked at all three of these factors in a sample of highly active middle-aged and older adults. Therefore, the current study was designed to assess fitness level and cognitive performances in highly active middle-aged and older individuals, in order to explore if fitness training has a positive effect on EF control in a computerized dual-task. In addition, we separated our sample into middle-aged adults (49–59 years) and older adults (60–70 years) in order to determine whether the aging process influenced the relationship between fitness level, EF, and cardiac autonomic control. Based on evidence that high fit people exhibit a greater cardio-respiratory fitness (CRF) and greater parasympathetic cardiac control, we hypothesized that within our active sample, those that were more physically fit would perform better in divided attention conditions, than individuals with lower physical fitness levels. We also expect that EF control advantage will be related to a greater parasympathetic cardiac autonomic control in higher fit individuals in comparison to lower fit individuals.

2. Method

2.1. Participants

Forty-two highly active individuals aged between 49 and 70 years of age participated in this study. All participants signed a written statement of informed consent. Participants were members of running or biking groups of Masters Athletes' organizations and participating in competitions on a regular basis for at least 5 years. A neuropsychologist and a physician performed the screening procedure and the exclusion criteria were the following:

- smokers, and any major surgery six months prior to the experiment,
- any neurological or psychiatric disorders and no medications known to affect cognition,
- any signs of dementia or depression, assessed by the Mini-Mental State Examination (scores had to be 26 and above; for "normal" cognitive function on a global test of cognition (Crum, Anthony, Bassett, & Folstein, 1993), and the Geriatric Depression Scale (scores had to be below 11; to ensure that there were no cases of mild, moderate or severe depression in our sample, as this is known to affect cognitive function; (Yesavage et al., 1982; Fiske, KaslGodley, & Gatz, 1998)
- any perceptual impairment evaluated by a questionnaire on auditory and visual function,
- presence of cardiovascular disease.
- Finally, all participants completed the modified Questionnaire of aptitude to physical activity (QAA-P) in order to identify any individual that may be put at risk when performing a physical