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# Improvements in cognition and associations with measures of aerobic fitness and muscular power following structured exercise

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ABSTRACT

*Objectives:* Cognition, along with aerobic and muscular fitness, declines with age. Although research has shown that resistance and aerobic exercise may improve cognition, no consensus exists supporting the use of one approach over the other. The purpose of this study was to compare the effects of steady-state, moderate-intensity treadmill training (TM) and high-velocity circuit resistance training (HVCRT) on cognition, and to examine its relationships to aerobic fitness and neuromuscular power.
*Methods:* Thirty older adults were randomly assigned to one of three groups: HVCRT, TM, or control. Exercise groups attended training 3 days/wk for 12 weeks, following a 2 week adaptation period. The NIH Cognitive Toolbox was used to assess specific components of cognition and provided an overall fluid composite score (FCS). The walking response and inhibition test (WRIT) was specifically used to assess executive function (EF) and provided an accuracy (ACC), reaction time (RT) and global score (GS). Aerobic power (AP) and maximal neuromuscular power (MP) were measured pre- and post-intervention. Relationships between variables using baseline and mean change scores were assessed.
*Results:* Significant increases were seen from baseline in ACC (MD = 14.0, SE = 4.3, $p$ = .01, d = 1.49), GS (MD = 25.6, SE = 8.0, $p$ = .01, d = 1.16), and AP (MD = 1.4, SE = 0.6, $p$ = .046, d = 0.31) for HVCRT. RT showed a trend toward a significant decrease (MD = −0.03, SE = 0.016, $p$ = .068, d = 0.32) for HVCRT. No significant within-group differences were detected for TM or CONT. Significant correlations were seen at baseline between AP and FCS, as well as other cognitive domains; but none were detected among change scores. Although no significant correlation was evident between MP and FCS or GS, there was a trend toward higher MP values being associated with higher FCS and GS scores.
*Conclusions:* Our results support the use of HVCRT over TM for improving cognition in older persons, although the precise mechanisms that underlie this association remain unclear.

## 1. Introduction

Age related cognitive decline is a common process, beginning as early as age 45 and progressing exponentially throughout the human lifespan (Singh-Manoux et al., 2012). Exercise has been shown to ameliorate symptoms associated with senescence in a variety of studies (Tivadar, 2017). Despite this consensus, the type of exercise (aerobic and anaerobic), dosing patterns (intensity, duration and frequency), and supporting physiological changes remain undetermined (Saez de Asteasu et al., 2017). Though many authors suggest aerobic training is optimal (Gregory et al., 2013; Fabre et al., 2002), others support the value of concurrent (endurance and resistance training) or multi-component training (aerobic fitness, strength, balance etc.) (Coelho et al., 2013) over mono-targeted designs (Saez de Asteasu et al., 2017). Therefore, there is a need to explore how different forms of exercise can impact cognition, and more specifically, which form of exercise produces the greatest improvements.

An important consideration when evaluating cognition, especially if incorporating the executive function (EF) testing components is testing methodology. Typically, EF assessments utilize either paper and pencil questionnaires or digital display systems that require the use of eye-keyboard activity. Although these approaches can be used to accurately assess EF processes, findings may not translate into real world scenarios involving movement and functional abilities. To address this, the

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current study utilized the recently developed Walking Response and Inhibition Test (WRIT; Leyva et al., 2017), which integrates gross motor control and a standardized digital display system to assess the EF domains of cognitive speed flexibility, response selection, inhibition, and capacity to initiate voluntary movement.

Addressing EF is particularly important when considering the observed decline in cognitive and functional ability associated with aging (Johnson et al., 2007; Raz and Rodrigue, 2006; Bherer et al., 2013). Diminished EF (Royall et al., 2004) and muscular power (Foldvari et al., 2000; Reid et al., 2014; Izquierdo and Cadore, 2014) are primary factors influencing the decline in functional status in elderly populations. According to a 2010 report by the U.S. Census Bureau, 39.4% of adults over the age of 65 report functional limitations that may interfere with ambulation and 12% reported limitations with at least one activity of daily living (ADL; Brault, 2012). Seniors living independently must maintain certain aptitudes (i.e. ambulating, grocery shopping, bathing, cleaning the house, etc.) to care for themselves and sustain their daily routines. Consequently, finding ways to attenuate age-related EF and muscular power decline can have a significant impact on the maintenance of an independent lifestyle.

Age-related senescence and cognitive impairment may be explained by progressive deterioration of white matter microstructure and other subcortical nuclei, expansion of cerebral spinal fluid (CSF), abatement of the cerebral parenchyma and volumetric changes in the neostriatum, hippocampus, and cerebellum (Erickson and Kramer, 2009; Raz and Rodrigue, 2006). As the striatum and cerebellum are vital to movement execution, any degeneration of these structures may lead to compromised motor control and declines in EF.

Since neuromuscular deterioration is one of the first signs of decreased power output (Reid et al., 2014; McKinnon et al., 2015) and atrophy in areas associated with neuromuscular control accrue with age (Raz and Rodrigue, 2006), a potential relationship may exist between age-related declines in muscular power and EF. Notably, exercise has been found to enhance a variety of functional and cognitive tasks, and research has shown that brain regions exclusively dedicated to EF appear to be especially sensitive to exercise training (Kramer et al., 2005; Hillman et al., 2008; Saez de Asteasu et al., 2017).

Currently there is a growing body of literature supporting the use of resistance (Cassilhas et al., 2007; Chang et al., 2012; Liu-Ambrose et al., 2010), aerobic (Albinet et al., 2010; Kramer et al., 1999; Smiley-Oyen et al., 2008; Guiney and Machado, 2013), and multicomponent (i.e. stretching, resistance and aerobic based) training approaches (Nouchi et al., 2014; Forte et al., 2013; Saez de Asteasu et al., 2017) to improve EF in elderly adults. For example, resistance training programs ranging from 3 to 12 months have been shown to improve selective attention, conflict resolution (Liu-Ambrose et al., 2010), inhibitory capacity (Forte et al., 2013), short-term and long-term memory (Cassilhas et al., 2007), and reaction time (Tsai et al., 2015). Alternatively, 6–10 months of aerobic exercise has been shown to increase cortical activity in areas associated with attentional control (Colcombe et al., 2004), task switching abilities (Kramer et al., 1999), inhibition and working memory (Smiley-Oyen et al., 2008).

The cardiovascular fitness hypothesis suggests that aerobic capacity is the mediator that explains the relationship between physical exercise and improved cognitive performance (North et al., 1990). Mechanisms that have been postulated to contribute to this observed improvement are: increased cerebral blood flow, alterations in neurotransmitter release, and altered arousal (Gligoroska and Manchevska, 2012). There is, however, insufficient evidence to support this relationship as results differ among studies. A recent meta-analysis conducted by Kelly et al. (2014) revealed that findings between randomized controlled trials are inconsistent and often in stark contrast to epidemiological, cross-sectional, and neuroimaging studies. The authors postulated that baseline physical performance, length of intervention and follow-up, and the efficacy and adherence to any given intervention may contribute to such conclusions. Furthermore, the optimal intervention lengths and the precise dose-response relationships required to achieve such benefits, once again, remain to be determined (Chang et al., 2012; Kelly et al., 2014; Smith et al., 2010; Young et al., 2015; Etnier et al., 2006).

Over the past two decades, there has been a proliferation of research surrounding resistance-training to increase functional activities and cognition. Specifically, studies have demonstrated that high-velocity resistance training can promote greater improvements in balance (Orr et al., 2006) and functional outcome measures (Miszko et al., 2003; Bottaro et al., 2007; Reid and Fielding, 2012) than standard strength training programs. Additionally, our laboratory has demonstrated that high-velocity resistance training can produce meaningful increases in measures of cognition including working memory and processing speed (Strassnig et al., 2015). The use of high-intensity resistance training, where loads are progressively increased rather than velocity, can positively enhance EF (Best et al., 2015; Liu-Ambrose et al., 2010); however, there is a paucity of research examining the effects of high-velocity resistance training on EF. Given that intensity during resistance training can be modulated through changes in load and movement velocity, and most studies examining resistance training and cognition have used loading to increase intensity, research using velocity-specific increases in intensity is warranted.

Although physical activity has been shown to improve several components of cognition, including EF, using a variety of modalities, to our knowledge, no study has compared the effects of a steady-state, moderate-intensity treadmill program (TM) to a high-velocity circuit resistance training program (HVCRT) in an elderly population. Furthermore, we could find no study that established a relationship between exercise-induced changes in neuromuscular power and cognition.

Therefore, the primary purpose of this study was to compare the effects of TM training to HVCRT on cognitive domains. A secondary goal was to examine the relationships of cognition to aerobic fitness and neuromuscular power. We hypothesized that both groups would make significant improvements in oxygen consumption, neuromuscular power, and cognition; however, the individuals participating in the HVCRT group would demonstrate greater increases in these measures than TM and control (CONT). Further, we postulated that increases in oxygen consumption and neuromuscular power would be positively correlated to improvements in multiple cognitive domains, including EF.

## 2. Materials & methods

### 2.1. Study design

The study employed a 14-week randomized, controlled, design to assess cognitive performance (including EF), aerobic (AP) and neuromuscular power (MP), and secondarily, body weight and fat-free mass, in independently living older persons.

### 2.2. Participants

Twenty-two women (age: 69.3 ± 8.1 years; height: 2.58 ± 0.13 m; body weight: 81.1 ± 12.5 kg) and eight men (age: 73.0 ± 5.4 years; height: 3.08 ± 0.32 m; body weight: 101.4 ± 5.8 kg) were recruited to the study. Subjects were stratified in descending order by sex, Mini Mental State Exam (MMSE) scores, education level, hypertension, dyslipidemia and depression scores, and randomized among groups. Sample size estimation was based on previous studies using the Stroop test as a primary outcome measure. The NIH Dimensional Change Card Sort (DCCS) test, a variation of the Stroop test, was used as a primary variable in the current study. Therefore, we used the results reported by Anderson-Hanley et al. (2010) for our power analysis. An ANCOVA model was used for the analysis. A minimum power of 0.80, an effect size of 0.54, and an alpha level of 0.05 yielded a total sample size of 30 participants. Participants