Psychology of Sport and Exercise 24 (2016) 118–127

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

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

Effects of motor-cognitive coordination training and cardiovascular training on motor coordination and cognitive functions

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ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form
25 December 2015
Accepted 20 January 2016
Available online 27 January 2016

Keywords:
Exercise
Cardiovascular training
Coordination training
Cognitive plasticity
Executive functions

ABSTRACT

Objectives: Numerous recent studies showed that physical training can enhance cognitive abilities, such as attention, spatial ability, memory performance, and executive functions. However, most of these studies focused on the efficiency of cardiovascular training, whereas evidence for combined motor-cognitive training emphasizing coordination abilities is scarce. Therefore, the aim of the present study was to investigate the effects of motor-cognitive coordination training and moderate cardiovascular training on cognitive functions and to test whether these effects were related to participant's fitness level.

Design and method: We tested 50 physically active (mean age = 23.5 years, *SD* = 3.2) and 56 sedentary participants (mean age = 23.4 years, *SD* = 3.2) in a pretest-training-posttest design with 12 sessions of moderate cardiovascular training (≈60% HRmax) or motor-cognitive coordination training. The training groups were compared to a passive control group. At pretest and posttest, participants performed an untrained motor-cognitive coordination task, measures of executive control (cognitive flexibility, inhibition, working memory), spatial ability, and fluid intelligence.

Results and conclusions: We found improved coordination abilities in the coordination training group, but no transfer of training to cognitive measures in physically active participants. However, sedentary participants showed larger improvements in terms of inhibition in the coordination training group compared to the remaining groups, while the cardiovascular training group improved in cognitive flexibility compared to the remaining groups. In sum, there are positive but differential effects of cardiovascular training and coordination training on cognitive performance in sedentary young participants, suggesting that coordination training may be a useful intervention especially for individuals that cannot perform cardiovascular training.

1. Introduction

Many recent studies have shown that physical exercise can improve cognitive abilities: Cross-sectional work indicated that the level of physical fitness was associated with cognitive performance in various tasks measuring aspects of attention, spatial ability, memory performance, processing speed or executive functions like cognitive flexibility or inhibition control (e.g., Budde, Voelcker-Rehage, Pietrassyk-Kendziorra, Ribeiroc, & Tidowa, 2008; Chaddock, Pontifex, Hillman, & Kramer, 2011; Chang, Labban, Gapin, & Etnier, 2012; Ozel, Larue, & Molinaro, 2004; Pontifex, Scudder, Drollette, & Hillman, 2012). Moreover, longitudinal studies showed that physical training, particularly in the domain of cardiovascular training (e.g., running or swimming), resulted in improved cognitive performance from childhood to older age (e.g., Chapman et al., 2013; Davis et al., 2011; Dresen & Netelenos, 1983; Kramer & Erickson, 2007; Voelcker-Rehage, Godde, & Staudinger, 2011; for reviews, see Hillman, Erickson, & Kramer, 2008; McMorris & Hale, 2012). For instance, Dresen and Netelenos (1983) showed that a ten-week ergometer training lead to better performances in attention tasks in children with an attentional deficit compared to untrained peers. In older adults, meta-analytic evidence revealed

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http://dx.doi.org/10.1016/j.psychsport.2016.01.008
1469-0292/

significant positive effects of cardiovascular training in the domain of executive control and medium-sized effects regarding controlled processing, speed of processing, and spatial abilities (Colcombe & Kramer, 2003). Voelcker-Rehage et al. (2011) provided evidence for improved performances on tasks measuring aspects of executive functions and processing speed after a 12-month walking training in older adults. These positive effects of cardiovascular fitness on cognitive abilities have been explained by training-induced changes in the brain. Animal and human studies showed functional and structural changes in the brain as a response to cardiovascular training, pointing to neuronal plasticity (Chaddock et al., 2010, 2011; Colcombe et al., 2004; Ratey & Hagerman, 2009; Shors, 2013). These changes are assumed to result in improved cognitive performance.

The changes in cognitive performance after coordination training have so far received less scientific attention. It typically includes demands on motor abilities and cognitive abilities. So far, well controlled longitudinal studies investigating the effects of coordination training on cognitive performance are scarce. Grünke (2011) provided evidence for improvements in terms of attention and fluid intelligence in 9–12 year-old children with attentional deficits compared to untrained peers after 12 sessions of coordination training. Hötting et al. (2012) compared the effects of six-months coordination/stretching training to the effects of cardiovascular training in middle-aged sedentary adults. In contrast to a control group, both training groups benefitted in terms of episodic memory. While this improvement in episodic memory was more pronounced in the cardiovascular training group, the coordination training group improved more in terms of attention. Moreover, Voelcker-Rehage et al. (2011) found that performance improvements on an interference control task were larger after coordination training than after cardiovascular training in older adults. According to Hötting and Röder (2013), this advantage of coordination training over cardiovascular training may be attributed to the requirement to manage cognitive as well as physical demands during training. Thus, training on dual tasks from different modalities involving demands on the neurocognitive system and the skeletal muscles seems to be particularly efficient for improving executive control and attentional processes (Hötting & Röder, 2013; Kubesch & Walk, 2009; Weineck, Schreyer, & Schatz, 2010). Furthermore, there is evidence that these demands on the neurocognitive system can initiate functional and structural changes in the brain (for a review, see Voelcker-Rehage & Niemann, 2013). Niemann, Godde, and Voelcker-Rehage (2014) found that motor fitness was associated with hippocampal volume and that both a 12-month cardiovascular and coordination training led to increases in hippocampal volume in older adults. Moreover Taubert, Lohmann, Margulies, Villringer, and Ragert (2011) provided evidence for structural gray matter alterations and functional connectivity changes in prefrontal and supplementary-motor areas after six training sessions in a dynamic balancing task.

In sum, there are only a few studies directly comparing coordination training and cardiovascular training which makes it hard to contrast the effects of cardiovascular training and coordination training on cognitive performance. Nevertheless, these studies suggest that there may be positive but differential effects of cardiovascular training and coordination training on cognitive performance and functional and structural changes in the brain.

So far, most training studies investigated samples of children or older adults and focused on compensatory effects of cardiovascular training on age-related differences in cognitive development or cognitive aging (e.g., Chang et al., 2012; Chapman et al., 2013; Dresen & Netelenos, 1983; Grünke, 2011; Hillman et al., 2008; Hillman & Schott, 2013; Jansen, Lange, & Heil, 2011; Lange, 2009; Voelcker-Rehage et al., 2011). As a consequence, there are only very few studies investigating healthy young adults. Draganski et al. (2004), for instance, found structural changes in brain areas supporting visuo-spatial abilities after three months of juggling training in young adults. However, this study did not provide evidence for improvements in the performance of cognitive tasks.

The aim of the present study was to test the effects of two types of physical training (coordination and cardiovascular) on (a) coordination abilities and (b) cognitive functions in younger adults as compared to a passive control condition (transfer). We expected larger improvements on the untrained coordination task in the coordination training group than in the remaining groups (cf. Hötting & Röder, 2013). With respect to the transfer of cardiovascular and motor-cognitive coordination training to cognitive abilities, we expected larger pretest-to-posttest improvements in both training groups than in the control group (cf. Colcombe et al., 2004; Voelcker-Rehage et al., 2011). Finally, we also investigated whether these transfer effects were different (c) as a function of training protocol (coordination vs. cardiovascular). Given that previous studies found better performance on cognitive and motor coordination tasks in professional athletes than in untrained non-athletes (Jansen, Lehmann, & Van Doren, 2012; Ozel et al., 2004) we explored training-related benefits in physically active and sedentary participants by means of two separate experiments: The first one included physically active participants that regularly engaged in physical activity. The second experiment included physically inactive participants that rarely or never engaged in physical activity.

2. Method

2.1. Participants

2.1.1. Experiment 1

Fifty individuals regularly following an exercise regimen participated in Experiment 1. They were recruited via advertisements posted on campus and distributed through a university mailing list. Participants in the two training groups (see below) received 65 EUR for participating in the pretest, posttest and 12 training sessions; participants in the control group received 20 EUR for participating in the pretest and posttest sessions. To ensure that all participants exercised regularly, they completed a questionnaire assessing habitual physical activity. Exclusion criteria were color blindness, achromatopsia, injuries preventing physical activity, chronic physical or psychiatric diseases, psychotropic medication, and blood pressure medication assessed by a biographic questionnaire. Active participants of experiment 1 and sedentary participants of experiment 2 were recruited together. Based on their answers on a questionnaire measuring their habitual physical activity they were assigned to the group of active participants (experiment 1) or the group of sedentary participants (experiment 2). Participants were matched for age and gender and then randomized into a motor-cognitive coordination training group, a moderate cardiovascular training group, or a passive control group. Five participants had to be excluded from the analysis because they failed to complete the exercise regimen. The final sample consisted of 16 (9 male) participants in the coordination training group, 19 (9 male) participants in the cardiovascular training group, and 10 participants (6 male) in the control group. Their mean age was 23.5 years ($SD = 3.2$) with a range of 18–31 years. The three groups were comparable in terms of age ($p = .49$) and gender ($p = .88$).

2.1.2. Experiment 2

The second experiment was conducted with 56 participants not regularly following an exercise regimen. Recruitment procedure, matching to the three groups, and exclusion criteria were the same