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EXERCISE-INDUCED CHANGES IN BASAL GANGLIA VOLUME AND COGNITION IN OLDER ADULTS

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Abstract—Physical activity has been demonstrated to diminish age-related brain volume shrinkage in several brain regions accompanied by a reduction of age-related decline in cognitive functions. Most studies investigated the impact of cardiovascular fitness or training. Other types of fitness or training are less well investigated. In addition, little is known about exercise effects on volume of the basal ganglia, which, however, are involved in motor activities and cognitive functioning. In the current study (1) we examined the relationships of individual cardiovascular and motor fitness levels with the volume of the basal ganglia (namely caudate, putamen, and globus pallidus) and selected cognitive functions (executive control, perceptual speed). (2) We investigated the effect of 12-month training interventions (cardiovascular and coordination training, control group stretching and relaxation) on the volume of the respective basal ganglia nuclei. Results revealed that motor fitness but not cardiovascular fitness was positively related with the volume of the putamen and the globus pallidus. Additionally, a moderating effect of the volume of the basal ganglia (as a whole, but also separately for putamen and globus pallidus) on the relationship between motor fitness and executive function was revealed. Coordination training increased caudate and globus pallidus volume. We provide evidence that coordinative exercise seems to be a favorable leisure activity for older adults that has the potential to improve volume of the basal ganglia.

Key words: brain aging, physical activity, motor fitness, cardiovascular fitness, basal ganglia, cognition.

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Abbreviations: adj, adjusted; AerTGE, Aerobic gas exchange threshold; AnTGE, Anaerobic gas exchange threshold; APOE ε4, apolipoprotein E ε4; HR, heart rate; ICC, intraclass correlation coefficient; ICV, intracranial volume; $p\eta^2$, partial eta-square; ROI, region of interest; TR, repetition time.

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INTRODUCTION

Regular physical activity – specifically cardiovascular training – has been suggested to positively affect brain function, structure and cognitive performance in older adults (Kramer et al., 2006; Hillman et al., 2008; Ruscheweyh et al., 2011). Although, like cortical brain regions (cf. Raz et al., 2005; Fjell and Walhovd, 2010), also the basal ganglia caudate, putamen, and globus pallidus show accelerated annual volume decline in older age (Raz et al., 2003), so far, only two studies examined the influence of cardiovascular fitness level or training on basal ganglia volume in older adults. Results of these studies are divergent. In a cross-sectional study, Verstynen et al. (2012) revealed cardiovascular fitness to be positively related to the volume of the caudate, putamen and globus pallidus as well as to task-switching performance. The relationship between the three factors revealed that a higher cardiovascular fitness predicted better cognitive flexibility through greater gray matter volume in the striatum. Erickson et al. (2011), on the contrary, revealed no significant effects of a 12-month cardiovascular training on caudate volume.

Recent research provided evidence that not only cardiovascular fitness and cardiovascular training (activities like walking, bicycling, swimming requiring metabolic and energetic processes), but also motor fitness and coordination training (cf. activities like balancing, reacting to objects/persons, eye–hand coordination, arm–leg coordination requiring perceptual and higher-level cognitive processes and rely on information processing; Voelcker-Rehage and Niemann, 2013 for further definitions) facilitate brain function and cognitive performance in older adults (Flegal and Reuter-Lorenz, 2010; Voelcker-Rehage et al., 2010, 2011). Considering the involvement of the dorsal part (the ventral part is more associated with reward processing) of the basal ganglia in motor learning (Jueptner and Weiller, 1998; Floyer-Lea and Matthews, 2004; Puttemans et al., 2005; Doyon et al., 2009), one might argue that forms of physical activity, that rely more on motor-demanding movements, might also have a greater impact on basal ganglia volume than cardiovascular activity has. In this vein, recent findings in young adults suggest that continuous basketball training (Park et al., 2011), professional ballet dance training (Haenggi et al., 2010), professional diving training (Wei et al., 2009) and golf training experience (Jäncke et al., 2009) reveal an impact on striatal (putamen or caudate) volume.

First, we analyzed a cross-sectional sample of older adults to investigate whether cardiovascular fitness and motor fitness were associated with volume of basal ganglia (caudate, putamen, globus pallidus) separately and as a whole and whether these associations differed in regard to type of fitness. Further, we examined whether basal ganglia volume in older adults had a moderating effect on the relationship between fitness and cognitive functioning (executive functioning and perceptual speed).

Second, we analyzed a subsample of the same dataset with respect to the effects of a 12-month either cardiovascular or coordination training, respectively, on the volume of the same subcortical structures. A control group exercised stretching and flexibility. In addition, we collected data on cognitive performance, namely executive control (Flanker task) and perceptual speed (Visual Search task) and related changes in cognitive performance to volume changes in basal ganglia.

EXPERIMENTAL PROCEDURES

Participants

Ninety-two healthy older adults between 62 and 89 years of age were recruited in the Bremen (Germany) area from a member register of a German health insurance company (DAK) or through newspaper advertisements to participate in the *Old Age on the Move* project. Before study inclusion, participants were screened for any history of cardiovascular disease, neurological disorder (e.g., self-report of neurological diseases such as brain tumor, Parkinson's disease, stroke), any other motor or cognitive restriction (a score of less than 27 in the Mini Mental Status Examination, MMSE, Folstein et al., 1975) or metal implants. One participant had to be excluded due to cognitive impairment (MMSE < 27). All subjects participated voluntarily in the study and provided written informed consent to the procedures of the study, which was approved by the ethics committee of the German Psychological Society. The study conforms to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Further screenings. Participants were asked about their demographics and health and were tested for normal vision (Freiburg Visual Acuity Test, Bach, 2007) and hearing (simultaneous auditory thresholds at multiple frequencies for both ears, presentation software: Neurobehavioral Systems, Albany, Canada, Yund, 2003). IQ was measured with a test battery from the Berlin aging study (cf. Li et al., 2004). Seven tests were used reflecting five primary intellectual abilities: (a) Perceptual speed, measured by the mean performance of Digit-Symbol Substitution and Identical Picture tests, (b) reasoning, measured by the mean performance of tests of Figural Analogies and Letter Series, (c) memory, measured by Paired Associate test, (d) verbal fluency, measured by the test of naming names of animals, and (e) verbal knowledge, measured by Vocabulary test. Performance scores were transformed into *T* scores ($M = 50$, $SD = 10$) and a mean intelligence index was calculated (cf. Table 1). No participant had to be excluded due to these criteria.

Cross-sectional sample. For cross-sectional data analysis, we had to exclude ten participants due to incomplete MRI data or data of quality being too low for structural data analysis (e.g., movement artifacts or too low contrast between gray and white matter which made manual demarcation of basal ganglia nuclei unfeasible), and ten participants due to incomplete motor data. One participant had to be excluded because of showing Flanker performance of more than 3.29 SD below the average (Tabachnick and Fidell, 2001). The remaining 70 participants had a mean age of 68.53 years (SD = 3.58; range 62–79 years; 52 females).

Intervention groups. Participants were randomly assigned to two experimental groups and a control group with respect to their place of residence and participated in a 12-month intervention study. Besides the participants that were excluded from the cross-sectional analysis ($n = 21$), participants who were absent for more than one test day and/or more than 25% of the training sessions ($n = 26$; calculated independently for each half year of the study) were excluded from data analysis. Eight more participants had to be excluded because structural MRI data at test session *t*2 and *t*3 were of a quality too low for brain volume analysis (see above). The remaining group consisted of 36 participants that had a mean age of 68.68 years (SD = 3.8; range 62–79 years; 25 females; cardiovascular training: $N = 13$, 10 females; coordination training: $N = 14$, 10 females; control group: $N = 9$, 5 females). Participants of the experimental and the control groups were statistically similar to one another on measures of age, years of formal education, intelligence index, health, physical and social activity index, BMI, hypertension, and estrogen replacement therapy (for women only; always $F(2, 33) > 2.43$, $p > .11$) (cf. Table 1) and were controlled for sample attrition bias from *t*1 to *t*3 (Voelcker-Rehage et al., 2011). As described in Voelcker-Rehage et al. (2011), only small sample selectivity was found for age (remaining participants were older), health (remaining participants were healthier), and positive affect (remaining participants were more positive). Given the size of the effects, it seems viable to conclude that findings obtained with the *t*3 sample may be generalized to the *t*1 parent sample.

Fitness assessments

Motor fitness at baseline was assessed by using a heterogeneous battery of eight motor tests representing four domains of motor fitness (cf. also Voelcker-Rehage et al., 2010): movement speed (hand tapping (Oja and Tuxworth, 1995), feet tapping (Voelcker-Rehage and Wiertz, 2003), 30-s chair stand test (Rikli and Jones, 1999), and agility (Adrian, 1981)), reaction speed (stick–fall-test (Ehrler and Huth, 2000)), balance (backward beam walk (Kiphard and Schilling, 1974) and one-leg-stand with eyes open and closed (Ekdahl et al., 1989))