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ABSTRACT

Walking is a complex task requiring interplay of neuromuscular, sensory, and cognitive functions. Owing to the age-related decline in cognitive and physical functions, walking may be compromised in older adults. For cognitive functions, especially poor performance in executive functions, is associated with slow walking speed. Hence, the aim of this study was to investigate the associations between different sub-domains of executive functions and physical functions and whether the associations found differ between men and women. Multiple linear regression analysis was performed on data collected from 314 community-dwelling, older adults who did not meet physical activity guidelines but had intact cognition. Our results showed that while executive functions were associated with gait and lower extremity functioning, the associations depended partly on the executive process measured and the nature of the physical task. Moreover, the associations did not differ between the sexes.

Key words: cognition, gait, dual-task cost, aging, sex differences

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Background

2 Walking is a complex task which is based on interplay of neuromuscular, sensory and
3 cognitive functions (Holtzer et al., 2006; Yogev-Seligmann et al., 2008). As physical and
4 cognitive functions decline with aging, walking, especially in more challenging conditions,
5 may be compromised in older adults (Shumway-Cook et al., 2007). Reduced gait speed and
6 cognitive functioning are both important determinants of health that are associated with poor
7 health outcomes, disability, and mortality. A recent study suggests that the relationship
8 between these determinants is bidirectional and that they are mutually capable of accelerating
9 each other's development (Basile & Sardella, 2020). It has also been indicated that the
10 presence of both reduced gait speed and cognitive impairment is more predictive of future
11 disability and mortality than either of these determinants alone (Grande et al., 2020).

12 Poor cognition, especially poor performance in executive functions, i.e., higher-level
13 functions that allow flexible goal-directed action and problem solving, has been found to be
14 associated with slow gait speed (Morris et al., 2016). According to Miyake et al. (2000)
15 executive functions include cognitive processes such as the ability to update and monitor
16 working memory representation (updating), the ability to shift attention between tasks (set
17 shifting) and the ability to inhibit over-learned stimulus response (inhibition).

18 Several brain regions are involved in regulating gait and executive functions.
19 According to Grande et al. (2019), gait relies on interplay between prefrontal, motor and
20 posterior parietal cortices, sub-cortical areas and more peripheral structures. From the
21 executive functions, updating, set-shifting and inhibition have been shown to increase
22 activation in the frontoparietal network (including e.g. dorsolateral prefrontal cortex), the
23 cingulo-opercular network and the Striatum (Wu et al., 2020). It has been hypothesized that

1 the partially overlapping anatomical locations and neuronal networks, mainly in the
2 prefrontal (Morris et al., 2016) and parietal areas, may be underlying causes of the
3 association between executive function and gait parameters (Poole et al., 2019).

4 Previous research investigating the associations between different subdomains of
5 executive functions and gait have reported partially conflicting results. Associations between
6 better performance in updating, set shifting or inhibition and faster gait speed or better lower
7 extremity functioning have been reported in some (Berryman et al., 2013; Coppin et al.,
8 2006; Demnitz et al., 2018; Herman et al., 2011; Morris et al., 2016; Soumare et al., 2009)
9 but not all studies (Hausdorff et al., 2005; Valkanova et al., 2018). Thus, there is no
10 consistent knowledge, if some subdomain of executive function is more strongly associated
11 with different types of walking or physical performance than others.

12 To perform a cognitive task simultaneously with a physical task, such as walking,
13 requires the allocation of limited cognitive processing resources. Walking-related dual-
14 tasking thus affects walking parameters, slows down gait speed, and negatively impacts
15 cognition (Menant et al., 2014). Due to the anatomical overlap regulating gait speed and
16 executive functions, decrements in dual-task performance may be due to competition for the
17 same resources.

18 Earlier studies that have investigated sex differences in executive functions have
19 shown mixed results. One study found sex differences to be sub-domain specific: women
20 outperformed men in fluent language production and in a task requiring working memory
21 updating, whereas no sex differences were observed in set-shifting (McCarrey et al., 2016).
22 Grissom & Reyes (2019), in turn, suggest that sex is not the primary factor influencing
23 performance in executive functions, and that the differences between the sexes may be more

1 This cross-sectional study utilized baseline data gathered for a randomized controlled
2 trial (The PASSWORD study, ISRCTN52388040). A detailed description of the study design
3 and recruitment has been published earlier (Sipilä et al., 2018). Participants were randomly
4 selected from the Finnish National Registry. They were 70- to 85-year-old community-
5 dwelling men and women living in the city of Jyväskylä, Finland, who did not meet physical
6 activity guidelines (less than 150 min of moderate physical activity/week and no regular
7 resistance training) (Nelson et al., 2007) but were able to walk 500 meters without assistance.
8 Participants suffering from severe chronic or progressive diseases, severe musculoskeletal
9 problems, depressive mood (GDS-15>5 points and who, according to the participants
10 themselves and assessments by physicians and primary investigators, would not have the
11 resources to commit to the study), excessive (risk level) use of alcohol (more than 7 units per
12 week for women and 14 for men) or any other contraindications for physical training, or a
13 Mini Mental State Examination (MMSE) score below 24 points were excluded.

14 Finally, 314 individuals were recruited for the study. The study was implemented
15 according to the Declaration of Helsinki and approved by the Ethical Committee of the
16 Central Finland Health Care District (K-S shp Dnro 11U/2016). All participants signed an
17 informed consent before the baseline measurements.

18 **Measurements**

19 Physical functions: In the *10-meter maximal gait speed* test (maximal gait speed),
20 participants were asked to walk as fast as possible over the 10-meter course, with 2 to 3
21 meters allowed for acceleration. The time taken (s) to complete the walk was measured by
22 photocells and gait speed (m/s) calculated. This test requires additional physical effort and is
23 more sensitive to different levels of cognition than habitual gait speed (Fitzpatrick et al.,

1 2007). In the *20-meter habitual gait speed test* (habitual gait speed), participants were asked
2 to walk 20 meters at their habitual speed. The time (s) taken to complete the walk was
3 measured by photocells and gait speed (m/s) calculated. Reduced habitual gait speed is
4 associated with risk for disability and cognitive impairment (Abellan van Kan et al., 2009).
5 After the habitual gait speed test, participants were asked to repeat the walk again while
6 performing a visuospatial cognitive task (Menant et al., 2014). The visuospatial task involved
7 a display with three boxes set side by side and labelled A, B and C. Participants were asked to
8 visualize a star that randomly moved to the left or right from one box to another. After three
9 imagined movements, participants were asked to name the box containing the star.
10 Participants were informed about the random starting position of the star and the direction of
11 its movements through headphones continuously throughout the walking trial. Each new set
12 of three movements was announced within one second of the participant answering the
13 previous question. The difference between the two trials, *i.e.*, *dual-task cost*, was calculated.
14 Dual-task cost shows how the need to divide attention affects gait speed (Yogev-Seligmann
15 et al., 2008). In the *six-minute walking distance test* (6-min walking distance), participants
16 were asked to walk around a 20-meter indoor track for 6 minutes, their aim being to walk the
17 longest possible distance without risking their health. This test serves as a measure for
18 community walking and walking endurance (Manttari et al., 2018). Lower extremity
19 function, which is essential for walking, was measured with the *Short Physical Performance*
20 *Battery* (SPPB), which comprises three subtests: standing balance test, habitual gait speed test
21 and repeated chair-rise test (Guralnik et al., 1994). A sum score (0-12) was calculated, with
22 higher scores indicating better performance.

23 Executive functions: In the *Color-Word Stroop test* (Stroop), participants were asked
24 to name colors under different conditions (Graf et al., 1995). First, they were asked to name a
25 set of red, blue, or green colored letter x's as quickly as possible. They were then asked to

1 read words naming colors (e.g., red, blue) printed in black. Finally, they were required to
2 state the color named by a word printed in an incongruent color, e.g., the word “blue” printed
3 in red ink. The inhibition cost, i.e., the difference between the time taken to name the colors
4 and the time taken to complete the incongruent word-color trial was calculated. The Stroop
5 test assesses the ability to inhibit a practiced and over-learned stimulus response (word-
6 reading), and to react to the less trained task of color naming. In the *Trail Making Test* (TMT)
7 A, which assesses psychomotor speed, participants were instructed to draw a line from
8 number one to number two and so on up to number 25 (Reitan, 1958). In TMT B, which
9 assess mental flexibility and set shifting, participants were instructed to draw a line from
10 number one to the letter A and then from number two to the letter B and so on. The difference
11 in the time taken to complete the two tests (TMT B-A) was calculated and used as an
12 outcome. Updating and lexical access speed was assessed with the *Verbal Fluency test* (VF)
13 (Koivisto et al., 1992). In this test participants were asked to name as many words beginning
14 with P, A and S as possible in one minute and the number of words was summed.

15 Background variables: Information on *age and sex* were drawn from the Finnish
16 National Population register. Body height and weight were measured, and body mass index
17 was calculated. *Chronic diseases and medication* were self-reported and verified by the study
18 physician through Finland’s integrated patient information system. *Cognitive status* was
19 assessed with the MMSE, which is a tool commonly used for screening cognitive functions
20 among older adults (Folstein et al., 1975). The MMSE provides information about
21 registration, attention, calculation, recall and language. The maximum MMSE test score is 30
22 and scores above 24 indicate normal cognitive function. Information on falls during the
23 previous year, physical activity, education and smoking were self-reported and assessed by
24 validated questions. *Indoor and outdoor falls* during previous year were reported separately
25 as follows: 1=none, 2=once, 3=2-4 times, 4=5-7 times 5=8 times or more. On the basis of the

1 information received on these questions, participants were characterized as fallers (categories
2 2 to 5) and non-fallers (category 1). Self-reported physical activity was assessed on a seven-
3 point scale. Response options were: 1= I do not move more than is necessary in my daily
4 routines/chores; 2=I go for casual walks and engage in light outdoor recreation 1–2 times a
5 week; 3= I go for casual walks and engage in light outdoor recreation several times a week;
6 4= I engage 1–2 times a week in brisk physical activity (e.g. yard work, walking, cycling) to
7 the point of perspiring and some degree of breathlessness; 5 = Several times a week (3–5) I
8 engage in brisk physical activity (e.g. yard work, walking, cycling) to the point of perspiring
9 and some degree of breathlessness; 6= I do keep-fit exercises several times a week in a way
10 that causes rather strong shortness of breath and sweating during the activity; and 7= I
11 participate in competitive sports and maintain my fitness through regular training (Hirvensalo
12 et al., 2000). For the regression analysis, physical activity was re-categorized as high
13 (categories 5 to 7) medium (categories 3 and 4) and low (categories 1 and 2). Except for one
14 participant who had reported category 6, all the participants in the high physical activity
15 category (n=40) had reported category 5. No participant had reported category 7. Education
16 was categorized as low (primary school or less) medium (middle school, folk high school,
17 vocational school, or secondary school) or high (high school diploma or university degree).
18 Smoking categories were, never, former, and current. For the analysis, smoking status was re-
19 coded as smokers (former and current) and non-smokers.

20 **Statistical analyses**

21 The sample size of this study, calculated for the primary outcome of the RCT design,
22 i.e., 10-meter maximal gait speed, was 314. Participants' characteristics were expressed as
23 means and standard deviations (SD) for continuous variables and as frequencies (n) and
24 percentages (%) for categorical variables. Differences between men and women were tested

1 with the Mann-Whitney U-test for non-normally distributed continuous variables, with chi-
2 square test for categorical variables and independent samples t-test for normally distributed
3 continuous variables. To correct for the abnormal distribution of the dual-task cost we added
4 a constant of 1 + the absolute value of minimum of the variable (-1.724) before using the
5 BoxCox transformation with lambda equal to -0.39.

6 Associations between executive and physical functions and their interaction with sex
7 were assessed with multiple linear regression analyses. For the analysis, three model sets
8 were constructed to explain each physical function measurement. In the executive functions
9 main-effect models, the main predictors were executive function and sex. In the executive
10 functions-sex-interaction models, the main predictors were executive function, sex and
11 executive function-sex-interaction. In the sex-stratified models, the analyses were carried out
12 separately for women and men and the main predictor was executive function. Finally, we
13 adjusted the main-effect models and sex-interaction models for multiple testing using the
14 Bonferroni correction. When the sex-interaction p-value was non-significant, the parameters
15 of the main effects model produced the most parsimonious description of the associations
16 between executive functions and physical functions, and the results were interpreted from the
17 main-effects model (see parameters for main effects in Table 3).

18 Theoretically meaningful and available control variables education, age, MMSE
19 scores, level of physical activity and smoking were included in the models. Relationships
20 between physical and executive functions and the control variables were tested with the
21 Pearson correlation coefficient and Spearman's rank correlation coefficient (Table 2).

22 For regression models, two dummy variables were created from education and
23 physical activity. Normality of residuals was checked using quantile-quantile plots and

1 skewness and kurtosis statistics. Heteroskedasticity of residuals was assessed by regressing
2 squared residuals on the predictor variables. The degree of multicollinearity was assessed
3 using variance inflating factors (VIFs). Residual diagnostics suggested two outliers remained
4 for the outcome, dual-task cost, even after Box-Cox transformation. However, the sensitivity
5 analysis indicated that removing these subjects from the analysis would not lead to
6 substantial modification of the results, and hence we decided to retain the subjects in the
7 analysis. Analyses were performed using IBM SPSS statistics (version 26). The descriptive
8 and bivariate correlation analyses were considered explorative, and we set alpha to the
9 nominal 0.05 level. For the model-based tests of effects, we used the Bonferroni-corrected
10 alpha level set at 0.05

11 **Results**

12 Participant characteristics are shown in Table 1. Mean age was 75 years and 60% of
13 the subjects were women. Significant anthropometric differences were observed between
14 men and women. Women were more likely to have higher education status and slightly
15 higher MMSE scores than men. Men were likely to smoke more than women and perform
16 better in the physical function and dual-task tests, except for habitual gait speed. No
17 significant differences between men and women were found in Stroop or TMT B-A. Women
18 significantly outperformed men in VF (Table 1).

19 Of the selected control variables, age and education correlated with the physical
20 function measurements with the exception of dual-task cost, which did not correlate with age
21 or education. Age correlated with all executive functions except verbal fluency. Education
22 and MMSE scores correlated with all executive functions. Physical activity correlated with
23 all the physical function measurements except maximal gait speed and dual-task cost.

1 Physical activity showed no significant association with executive functions and MMSE
2 showed no significant association with physical functions. Smoking did not show a
3 statistically significant association with physical or executive functions. However, as
4 smoking is a known risk factor for poor physical and cognitive functioning, we decided to
5 retain it in the models (Table 2).

6 In the multiple linear regression analysis (Table 3), we first examined only
7 associations involving the main effects of executive function (significant main effect and
8 non-significant sex interaction). After adjusting the models for multiple comparisons, we
9 found that VF was associated with higher maximal and habitual gait speed ($\beta=0.273$ $p<0.001$,
10 $\beta=0.184$ $p=0.009$, respectively), longer 6-min walking distance ($\beta=0.242$, $p<0.001$) and
11 higher SPPB scores ($\beta=0.234$, $p<0.001$). TMT B-A was associated with higher SPPB scores
12 ($\beta=-0.236$, $p= p<0.001$). Stroop was not associated with any of the physical function tests. In
13 addition, all sex interactions were non-significant. Sex-stratified models are shown in
14 supplementary table 1.

15 Discussion

16 In this study conducted among community-dwelling older adults who did not meet
17 physical activity guidelines, we found that better performance in executive functions related
18 to updating and set shifting was associated with better walking performance and lower
19 extremity functioning. However, the ability to inhibit an over-learned stimulus response was
20 not associated with any of the physical function tests. In addition, we found non-significant
21 sex-interactions in the associations between physical and executive functions.

22 Earlier studies that have investigated the associations between executive functioning
23 and walking performance have reported partially conflicting results. Associations between

1 better performance in set shifting, updating and inhibition and faster gait speed or better
2 lower extremity functioning have been reported in some studies (Berryman et al., 2013;
3 Coppin et al., 2006; Demnitz et al., 2018; Herman et al., 2011; Soumare et al., 2009) while
4 other studies did not find these associations (Hausdorff et al., 2005; Kaye et al., 2012;
5 Valkanova et al., 2018). Our results suggest that among community-dwelling and relatively
6 healthy older people, executive functions related in particular to updating, but also to set-
7 shifting are associated with physical functions.

8 We found that updating and set shifting were associated with faster maximal and
9 habitual gait speed, longer distance travelled (updating) and better lower extremity
10 functioning (updating and set shifting), whereas no significant association was observed
11 between executive functions and dual-task cost in gait speed. These results suggest that safe
12 and stable walking and lower extremity functions requiring dynamic, reciprocal, rhythmic
13 and fluent sensorimotor performance may depend more on updating/lexical access speed and
14 mental flexibility than the ability to inhibit an over-learned stimulus response. As indicated
15 above, our findings highlight the dependency of the associations between physical and
16 executive functions on the type of executive processes and physical tasks measured and thus
17 may partly explain the conflicting results of prior studies (Berryman et al., 2013; Coppin et
18 al., 2006; Demnitz et al., 2018; Hausdorff et al., 2005; Herman et al., 2011; Kaye et al., 2012;
19 Valkanova et al., 2018)

20 Surprisingly, unlike previous studies that have reported associations between
21 executive functions and dual-task gait performance, at least when the concurrent cognitive
22 task is demanding (Liu-Ambrose et al., 2009; Menant et al., 2014), we found no association
23 between executive functions and smaller dual-task cost in gait speed. We assessed the dual-
24 task condition with a cognitively challenging visuospatial-motor task that has been found to

1 induce greater interference while walking than non-spatial tasks (Menant et al., 2014) and
2 were therefore surprised to find that the association between executive functions and dual-
3 task cost in gait speed was non-significant. However, a systematic review showed that the
4 visuo-spatial cognitive domain is associated with the postural control domain of gait rather
5 than pace, i.e., speed of gait (Morris et al., 2016). Moreover, Coppin et al. (2006) have
6 suggested that the cost associated with increased executive load during basic walking differs
7 by the nature of the dual task. We assessed dual-task gait performance in habitual gait speed,
8 which is not a physically challenging task, and this may have affected our results. It may be
9 that among well-functioning, relatively healthy older adults the association between
10 executive functions and dual-task performance is more prominent when both the cognitive
11 and physical task are simultaneously demanding.

12 The associations of sex differences with executive and physical functions were non-
13 significant. Prior research on this topic is limited. Best et al. (2016) found no sex differences
14 in the longitudinal associations between executive functions and habitual gait speed, whereas
15 Thibeau et al. (2019) reported that sex moderated the longitudinal associations of executive
16 functions with walking and balance. They suggest that the sex-dependent association of
17 physical activity and walking or balance, with executive functions is multifactorial, due to,
18 for example, age-related changes in neural networks and brain structure in the frontal cortex
19 that differ between the sexes (Crivello et al., 2014; Scheinost et al., 2015). In addition,
20 muscle and metabolic biomarkers affecting gait speed and cognition differ between men and
21 women. For example, sex-specific muscle and metabolic biomarkers have been shown to be
22 associated with changes in gait speed in both sexes whereas metabolic biomarkers were
23 shown to be associated with changes in cognitive functions only among men (Waters et al.,
24 2020). It should be noted that the earlier studies only measured habitual gait speed, which
25 does not necessarily reveal the known sex differences underlying gait speed, such as body

1 height and lower body muscle strength. Our results showing no sex differences in the
2 associations between gait speed and executive functions extend those reported by Best et al.
3 (2016) by showing no sex differences in the associations of gait speed tests differing in
4 difficulty and length with executive functioning among a sample of older adults who did not
5 meet physical activity guidelines. However, further studies are needed to confirm this result.

6 To further knowledge on the associations between cognitive and physical functions
7 among relatively healthy older people, we designed a measurement protocol with a
8 comprehensive array of executive and physical function measures. We included tests for
9 three subdomains of executive functioning that have been extensively used in studies among
10 older people. The measures of physical function traits used here are commonly used in
11 clinical settings and in aging research and known to predict adverse outcomes, e.g., disability,
12 cognitive impairment, falls and even mortality in older populations (Abellan van Kan et al.,
13 2009). These included a relatively simple measure, habitual gait speed over a short distance,
14 along with more physically and cognitively challenging tests, such as walking over a longer
15 distance either at maximal gait speed or under dual-task conditions, and a more complex
16 measure (SPPB) in which walking, balance and lower body muscle power scores are merged
17 into a composite score.

18 In addition to assessing gait and executive function with an extensive measurement
19 protocol, the strengths of this study include a representative sample of community-dwelling
20 older people who did not meet the physical activity guidelines and the measurements that are
21 widely used and considered to be suitable for assessing older adults. Moreover, the fact that
22 the measurements were conducted by the same investigators is likely to enhance the
23 reliability of the results.

- 1 physical tests among older adults: analyses from the InChianti study. *Age and Ageing*,
2 35(6), 619-624. 35/6/619 [pii]
- 3 Crivello, F., Tzourio-Mazoyer, N., Tzourio, C., & Mazoyer, B. (2014). Longitudinal
4 assessment of global and regional rate of grey matter atrophy in 1,172 healthy older
5 adults: modulation by sex and age. *PloS One*, 9(12), e114478.
6 10.1371/journal.pone.0114478 [doi]
- 7 Demnitz, N., Hogan, D. B., Dawes, H., Johansen-Berg, H., Ebmeier, K. P., Poulin, M. J., &
8 Sexton, C. E. (2018). Cognition and mobility show a global association in middle- and
9 late-adulthood: Analyses from the Canadian Longitudinal Study on Aging. *Gait &*
10 *Posture*, 64, 238-243. S0966-6362(18)30845-2 [pii]
- 11 Fitzpatrick, A. L., Buchanan, C. K., Nahin, R. L., Dekosky, S. T., Atkinson, H. H., Carlson,
12 M. C., Williamson, J. D., & Ginkgo Evaluation of Memory (GEM) Study Investigators.
13 (2007). Associations of gait speed and other measures of physical function with
14 cognition in a healthy cohort of elderly persons. *The Journals of Gerontology. Series A,*
15 *Biological Sciences and Medical Sciences*, 62(11), 1244-1251. 62/11/1244 [pii]
- 16 Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical
17 method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric*
18 *Research*, 12(3), 189-198. 0022-3956(75)90026-6 [pii]
- 19 Graf, P., Uttl, B., & Tuokko, H. (1995). Color- and picture-word Stroop tests: performance
20 changes in old age. *Journal of Clinical and Experimental Neuropsychology*, 17(3), 390-
21 415. 10.1080/01688639508405132 [doi]

- 1 Grande, G., Vetrano, D. L., Fratiglioni, L., Marseglia, A., Vanacore, N., Laukka, E. J.,
2 Welmer, A. K., & Rizzuto, D. (2020). Disability trajectories and mortality in older adults
3 with different cognitive and physical profiles. *Aging Clinical and Experimental*
4 *Research*, 32(6), 1007-1016. 10.1007/s40520-019-01297-1 [doi]
- 5 Grande, G., Triolo, F., Nuara, A., Welmer, A. K., Fratiglioni, L., & Vetrano, D. L. (2019).
6 Measuring gait speed to better identify prodromal dementia. *Experimental Gerontology*,
7 124, 110625. S0531-5565(19)30290-6 [pii]
- 8 Grissom, N. M., & Reyes, T. M. (2019). Let's call the whole thing off: evaluating gender and
9 sex differences in executive function. *Neuropsychopharmacology : Official Publication*
10 *of the American College of Neuropsychopharmacology*, 44(1), 86-96. 10.1038/s41386-
11 018-0179-5 [doi]
- 12 Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G.,
13 Scherr, P. A., & Wallace, R. B. (1994). A short physical performance battery assessing
14 lower extremity function: association with self-reported disability and prediction of
15 mortality and nursing home admission. *Journal of Gerontology*, 49(2), 85.
- 16 Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S., & Giladi, N. (2005). Walking is more
17 like catching than tapping: gait in the elderly as a complex cognitive task. *Experimental*
18 *Brain Research*, 164(4), 541-548. 10.1007/s00221-005-2280-3 [doi]
- 19 Herman, T., Giladi, N., & Hausdorff, J. M. (2011). Properties of the 'timed up and go' test:
20 more than meets the eye. *Gerontology*, 57(3), 203-210. 10.1159/000314963 [doi]

- 1 Hirvensalo, M., Rantanen, T., & Heikkinen, E. (2000). Mobility difficulties and physical
2 activity as predictors of mortality and loss of independence in the community-living
3 older population. *Journal of the American Geriatrics Society*, *48*(5), 493-498.
- 4 Holtzer, R., Verghese, J., Xue, X., & Lipton, R. B. (2006). Cognitive processes related to gait
5 velocity: results from the Einstein Aging Study. *Neuropsychology*, *20*(2), 215-223. 2006-
6 03817-009 [pii]
- 7 Kaye, J., Mattek, N., Dodge, H., Buracchio, T., Austin, D., Hagler, S., Pavel, M., & Hayes, T.
8 (2012). One walk a year to 1000 within a year: continuous in-home unobtrusive gait
9 assessment of older adults. *Gait & Posture*, *35*(2), 197-202.
10 10.1016/j.gaitpost.2011.09.006 [doi]
- 11 Koivisto, K., Helkala, E. L., Reinikainen, K. J., Hanninen, T., Mykkanen, L., Laakso, M.,
12 Pyorala, K., & Riekkinen, P. J. (1992). Population-based dementia screening program in
13 Kuopio: the effect of education, age, and sex on brief neuropsychological tests. *Journal*
14 *of Geriatric Psychiatry and Neurology*, *5*(3), 162-171. 10.1177/002383099200500306
15 [doi]
- 16 Liu-Ambrose, T., Katarynych, L. A., Ashe, M. C., Nagamatsu, L. S., & Hsu, C. L. (2009).
17 Dual-task gait performance among community-dwelling senior women: the role of
18 balance confidence and executive functions. *The Journals of Gerontology.Series A,*
19 *Biological Sciences and Medical Sciences*, *64*(9), 975-982. 10.1093/gerona/glp063 [doi]
- 20 Manttari, A., Suni, J., Sievanen, H., Husu, P., Vaha-Ypya, H., Valkeinen, H., Tokola, K., &
21 Vasankari, T. (2018). Six-minute walk test: a tool for predicting maximal aerobic power
22 (VO2 max) in healthy adults. *Clinical Physiology and Functional Imaging*,
23 10.1111/cpf.12525 [doi]

- 1 McCarrey, A. C., An, Y., Kitner-Triolo, M. H., Ferrucci, L., & Resnick, S. M. (2016). Sex
2 differences in cognitive trajectories in clinically normal older adults. *Psychology and*
3 *Aging, 31*(2), 166-175. 10.1037/pag0000070 [doi]
- 4 Menant, J. C., Sturnieks, D. L., Brodie, M. A., Smith, S. T., & Lord, S. R. (2014).
5 Visuospatial tasks affect locomotor control more than nonspatial tasks in older people.
6 *PloS One, 9*(10), e109802. 10.1371/journal.pone.0109802 [doi]
- 7 Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D.
8 (2000). The unity and diversity of executive functions and their contributions to complex
9 "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.
10 10.1006/cogp.1999.0734 [doi]
- 11 Morris, R., Lord, S., Bunce, J., Burn, D., & Rochester, L. (2016). Gait and cognition:
12 Mapping the global and discrete relationships in ageing and neurodegenerative disease.
13 *Neuroscience and Biobehavioral Reviews, 64*, 326-345. S0149-7634(15)30230-X [pii]
- 14 Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., Macera,
15 C. A., & Castaneda-Sceppa, C. (2007). Physical activity and public health in older
16 adults: recommendation from the American College of Sports Medicine and the
17 American Heart Association. *Medicine and Science in Sports and Exercise, 39*(8), 1435-
18 1445. 00005768-200708000-00028 [pii]
- 19 Poole, V. N., Lo, O. Y., Wooten, T., Iloputaife, I., Lipsitz, L. A., & Esterman, M. (2019).
20 Motor-Cognitive Neural Network Communication Underlies Walking Speed in
21 Community-Dwelling Older Adults. *Frontiers in Aging Neuroscience, 11*, 159.
22 10.3389/fnagi.2019.00159 [doi]

- 1 Reitan, R.,M. (1958). *Validity of the Trail Making Test as an Indicator of Organic Brain*
2 *Damage*10.2466/PMS.8.7.271-276
- 3 Scheinost, D., Finn, E. S., Tokoglu, F., Shen, X., Papademetris, X., Hampson, M., &
4 Constable, R. T. (2015). Sex differences in normal age trajectories of functional brain
5 networks. *Human Brain Mapping, 36*(4), 1524-1535. 10.1002/hbm.22720 [doi]
- 6 Shumway-Cook, A., Guralnik, J. M., Phillips, C. L., Coppin, A. K., Ciol, M. A., Bandinelli,
7 S., & Ferrucci, L. (2007). Age-associated declines in complex walking task performance:
8 the Walking InCHIANTI toolkit. *Journal of the American Geriatrics Society, 55*(1), 58-
9 65. JGS962 [pii]
- 10 Sialino, L. D., Schaap, L. A., van Oostrom, S. H., Nooyens, A. C. J., Picavet, H. S. J., Twisk,
11 J. W. R., Verschuren, W. M. M., Visser, M., & Wijnhoven, H. A. H. (2019). Sex
12 differences in physical performance by age, educational level, ethnic groups and birth
13 cohort: The Longitudinal Aging Study Amsterdam. *PloS One, 14*(12), e0226342.
14 10.1371/journal.pone.0226342 [doi]
- 15 Sipila, S., Tirkkonen, A., Hanninen, T., Laukkanen, P., Alen, M., Fielding, R. A., Kivipelto,
16 M., Kokko, K., Kulmala, J., Rantanen, T., Sihvonen, S. E., Sillanpaa, E., Stigsdotter-
17 Neely, A., & Tormakangas, T. (2018). Promoting safe walking among older people: the
18 effects of a physical and cognitive training intervention vs. physical training alone on
19 mobility and falls among older community-dwelling men and women (the PASSWORD
20 study): design and methods of a randomized controlled trial. *BMC Geriatrics, 18*(1),
21 215-0. 10.1186/s12877-018-0906-0 [doi]

- 1 Soumare, A., Tavernier, B., Alperovitch, A., Tzourio, C., & Elbaz, A. (2009). A cross-
2 sectional and longitudinal study of the relationship between walking speed and cognitive
3 function in community-dwelling elderly people. *The Journals of Gerontology.Series A,*
4 *Biological Sciences and Medical Sciences, 64(10), 1058-1065.* 10.1093/gerona/glp077
5 [doi]
- 6 Thibreau, S., McFall, G. P., Camicioli, R., & Dixon, R. A. (2019). Physical Activity and
7 Mobility Differentially Predict Nondemented Executive Function Trajectories: Do Sex
8 and APOE Moderate These Associations? *Gerontology, , 1-9.* 10.1159/000496442 [doi]
- 9 Valkanova, V., Esser, P., Demnitz, N., Sexton, C. E., Zsoldos, E., Mahmood, A., Griffanti,
10 L., Kivimäki, M., Singh-Manoux, A., Dawes, H., & Ebmeier, K. P. (2018). Association
11 between gait and cognition in an elderly population based sample. *Gait & Posture, 65,*
12 *240-245.* S0966-6362(18)31317-1 [pii]
- 13 Waters, D. L., Vlietstra, L., Qualls, C., Morley, J. E., & Vellas, B. (2020). Sex-specific
14 muscle and metabolic biomarkers associated with gait speed and cognitive transitions in
15 older adults: a 9-year follow-up. *GeroScience, 42(2), 585-593.* 10.1007/s11357-020-
16 00163-7 [doi]
- 17 Wu, T., Chen, C., Spagna, A., Wu, X., Mackie, M. A., Russell-Giller, S., Xu, P., Luo, Y. J.,
18 Liu, X., Hof, P. R., & Fan, J. (2020). The functional anatomy of cognitive control: A
19 domain-general brain network for uncertainty processing. *The Journal of Comparative*
20 *Neurology, 528(8), 1265-1292.* 10.1002/cne.24804 [doi]
- 21 Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function
22 and attention in gait. *Movement Disorders : Official Journal of the Movement Disorder*
23 *Society, 23(3), 329-42; quiz 472.* 10.1002/mds.21720 [doi]

Table 1

Participants Characteristics (Means and standard deviations or frequencies and percentages)

	All (n=314)	Women (n=188)	Men (n=126)	p
Age	74.5 ± 3.8	74.5 ± 3.8	74.4 ± 3.9	0.568 ^a
Height (m)	1.66 ± 0.09	1.61 ± 0.06	1.74 ± 0.06	<0.001 ^c
Weight (kg)	76.9 ± 14.2	71.9 ± 13.1	84.3 ± 12.5	<0.001 ^a
BMI	27.9 ± 4.7	28.0 ± 5.3	27.9 ± 3.6	0.394 ^a
Education (%):				0.027 ^b
Low	48 (15)	21 (11)	27 (21)	
Medium	200 (64)	122 (65)	78 (62)	
High	66 (21)	45 (24)	21 (17)	
Current physical activity (%)				0.227 ^b

Low	126 (40)	73 (39)	53 (42)	
Medium	148 (47)	95 (51)	53 (42)	
High	40 (13)	20 (11)	20 (16)	
Fall in the previous year (%)				0.231 ^b
Yes	164 (52)	93 (50)	71 (56)	
No	150 (48)	95 (51)	55 (44)	
Smoking status (%)				<0.001 ^b
Never smoker	191 (61)	135 (72)	56 (44)	
Former smoker	109 (35)	48 (26)	61 (48)	
Current smoker	14 (4)	5 (3)	9 (7)	
Number of the chronic diseases	2.4±1.5	2.4±1.6	2.6±1.5	0.344 ^a

MMSE (score)	27.6±1.5	27.8±1.5	27.5±1.4	0.049 ^a
SPPB (score)	10.1±1.5	9.8 ± 1.5	10.6 ± 1.4	<0.001 ^a
10m gait speed (m/s)	2.0± 0.4	1.9± 0.3	2.1 ± 0.4	<0.001 ^c
20m gait speed (m/s)	1.3 ± 0.2	1.3 ± 0.2	1.3 ± 0.2	0.148 ^c
6min walking distance (m)	475.4± 81.7	457.3 ± 70.3	502.4 ± 89.9	<0.001 ^c
Dual-task cost (s) ^d	1.25 ± 0.25	1.29 ± 0.24	1.20 ± 0.25	0.004 ^a
Stroop difference (s)	46.7 ± 25.0	46.5 ± 22.4	46.9 ± 28.6	0.770 ^a
TMT B-A (s)	88.0 ± 52.2 (n=313)	83.8 ± 50.8 (n=187)	94.4 ± 53.8	0.051 ^a
Verbal fluency test (words)	41.6 ± 13.0	44.4 ± 12.1	37.5 ± 13.2	<0.001 ^c

Note. BMI= body mass index, MMSE= Minimental State Examination, SPPB= Short Physical Performance Battery, TMT= the Trail Making Test. One participant was unable to perform TMT test due to hand pain.

^aMann-Whitney U-test, ^bChi-square, ^cIndependent samples t-test, ^dDistribution shifted by adding a constant of 2.724 and Box-Cox transformed with $\lambda = -0.39$.

Table 2.

Bivariate correlations between physical and executive function variables (columns) and background variables (rows).

		Maximal gait speed	Dual-task cost	Habitual gait speed	Walking distance	SPPB	Verbal fluency	TMT B-A	Stroop
Age^a	r	-0.29	0.07	-0.26	-0.33	-0.18	-0.05	0.28	0.15
	p	<0.001	0.222	<0.001	<0.001	0.002	0.427	<0.001	0.010
Education^b	rs	0.14	-0.07	0.12	0.14	0.17	0.33	-0.35	-0.15
	p	0.011	0.188	0.036	0.013	0.016	<0.001	<0.001	0.008
Physical activity^b	rs	0.07	0.05	0.18	0.20	0.18	-0.05	-0.03	0.03
	p	0.204	0.368	0.002	<0.001	0.002	0.394	0.576	0.647
MMSE^a	r	0.05	-0.05	0.05	0.04	0.05	0.19	-0.25	-0.11
	p	0.378	0.407	0.421	0.502	0.341	0.001	<0.001	0.043
Smoking^b	rs	-0.02	-0.06	-0.07	-0.10	<0.01	-0.01	<0.01	0.02
	p	0.693	0.336	0.194	0.102	0.951	0.836	0.997	0.768

Note, Correlation coefficients and p-values presented. ^aPearson correlation coefficient ^bSpearman's rank correlation coefficient

Table 3

Association between physical functions and executive functions among 70-85 years old men and women. Main effect coefficients are from main effects models for each executive function and sex-interaction p-values are from the sex-executive function interaction models.

	Maximal gait			Habitual gait			Dual-task cost ^a			6min walking			SPPB		
	speed			speed						distance					
	β	R ²	p	β	R ²	p	β	R ²	p	β	R ²	p	β	R ²	p
Main effects models															
VF	0.273	0.272	<0.001	0.184	0.127	0.009	-0.050	0.032	1.000	0.242	0.291	<0.001	0.234	0.184	<0.001
TMT B-A	-0.100	0.214	0.409	-0.111	0.108	0.360	0.144	0.046	0.121	-0.130	0.253	0.107	-0.236	0.178	<0.001
STROOP	-0.063	0.213	1.000	-0.052	0.101	1.000	0.110	0.042	0.267	-0.057	0.245	1.000	-0.058	0.142	1.000
Interaction effect models															
VF*sex			0.120			0.799			0.357			0.110			1.000
TMT B-A*sex			1.000			1.000			0.109			1.000			1.000
STROOP*sex			0.788			1.000			1.000			0.544			1.000

Note. Bonferroni-corrected p-value for five outcome variables. TMT=Trail making test, VF=verbal fluency test. In sex-interaction models reference was male. Control variables in models were age, education, level of physical activity, smoking and MMSE scores. ^aDistribution shifted by adding a constant of 2.724 and Box-Cox transformed with $\lambda = -0.39$.

