Cognitive functioning is more closely related to real-life mobility than to laboratory-based mobility parameters

Eleftheria Giannouli¹ · Otmar Bock² · Wiebren Zijlstra¹

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Abstract Increasing evidence indicates that mobility depends on cognitive resources, but the exact relationships between various cognitive functions and different mobility parameters still need to be investigated. This study examines the hypothesis that cognitive functioning is more closely related to real-life mobility performance than to mobility capacity as measured with standardized laboratory tests. The final sample used for analysis consisted of 66 older adults (72.3 ± 5.6 years). Cognition was assessed by measures of planning (HOTAP test), spatial working memory (Grid-Span test) and visuospatial attention (Attention Window test). Mobility capacity was assessed by an instrumented version of the Timed Up-and-Go test (iTUG). Mobility performance was assessed with smartphones which collected accelerometer and GPS data over one week to determine the spatial extent and temporal duration of real-life activities. Data analyses involved an exploratory factor analysis and correlation analyses. Mobility measures were reduced to four orthogonal factors: the factor ‘real-life mobility’ correlated significantly with most cognitive measures (between $r = .229$ and $r = .396$); factors representing ‘sit-to-stand transition’ and ‘turn’ correlated with fewer cognitive measures (between $r = .271$ and $r = .315$ and between $r = .210$ and $r = .316$, respectively),

and the factor representing straight gait correlated with only one cognitive measure ($r = .237$). Among the cognitive functions tested, visuospatial attention was associated with most mobility measures, executive functions with fewer and spatial working memory with only one mobility measure. Capacity and real-life performance represent different aspects of mobility. Real-life mobility is more closely associated with cognition than mobility capacity, and in our data this association is most pronounced for visuospatial attention. The close link between real-life mobility and visuospatial attention should be considered by interventions targeting mobility in old age.

Keywords Out-of-home mobility · Ageing · Life-space · Instrumented Timed Up-and-Go test · Capacity · Performance

Introduction

Mobility is a complex and multifaceted construct (Webber 2010; Wettstein et al. 2014b). It includes the ability to walk and move around, change or maintain body position, carry, move and handle objects but also more resource-intensive skills like out-of-home mobility on foot and moving around using transportation (World Health Organization 2005). Besides neuromechanical functions required for successful locomotion, mastering activities of daily living also depends on cognitive functions. From the control of routine gait, to planning and execution of complex movement sequences and interactions with traffic and ticket vending machines, cognitive abilities are crucial for all aspects of mobility. Indeed, increasing evidence indicates that, due to age-related changes in sensory motor and neuromechanical functions, mobility in older persons depends increasingly

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✉ Eleftheria Giannouli
e.giannouli@dshs-koeln.de

¹ Institute of Movement and Sport Gerontology, German Sport University Cologne, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany

² Institute of Physiology and Anatomy, German Sport University Cologne, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany

on cognitive resources. This has been documented in cross-sectional (Ble et al. 2005; Carlson et al. 1999) as well as in longitudinal studies (Buchman 2011; Soumaré 2009). Especially with regard to real-life mobility, cognitive status has been found to be more closely linked with out-of-home behavior than motivational resources (Wahl et al. 2013) and also to moderate the relationship between out-of-home behavior and well-being (Wettstein et al. 2014a).

Most studies investigating the relationship between cognition and mobility have measured overall cognitive functioning using screening tools for cognitive impairment, such as the MMSE (Crowe et al. 2010) and/or single measures of mobility like gait speed (Ble et al. 2005; Holtzer et al. 2006; Inzitari et al. 2007). However, regarding cognitive performance, it is important to use selected cognitive tests to look into specific cognitive domains which are necessary for mobility. Differentiation is also needed when it comes to measuring mobility. Recent studies have shown that mobility capacity (the highest possible level of functioning of an individual in a given domain at a certain moment) and mobility performance (what individuals do in their own current environment) (as defined in the International Classification of Functioning by the World Health Organization 2005) are two different aspects of mobility (Giannouli et al. 2016; van Lummel et al. 2015) which are therefore expected to be associated differently with specific cognitive domains.

Previous research has demonstrated a robust relationship between gait and executive functions (Martin et al. 2013; Yogev-Seligmann et al. 2008). However, gait has been assessed in standardized laboratory settings, which differ from real life in multiple respects: In everyday situations, persons often move in a complex and visually cluttered environment, they execute a non-repetitive sequence of activities (e.g., bus riding, then shopping, then visiting a café), often engage in multitasking (e.g., looking for a product on the shelves while avoiding collisions with other shoppers), respond to unexpected events (e.g., keeping balance when the bus driver hits the brake) and they pursue those activities not because they are instructed to do so, but in order to achieve some desirable goal. In other words, standardized laboratory settings typically lack ecological validity and findings may therefore not be fully transferrable to real life (Chaytor and Schmitter-Edgecombe 2003).

Most of the existing research examining the association between mobility and cognition has focused on either one cognitive domain or on one aspect of mobility at a time and mostly only on laboratory measures. Therefore, this study explores the relationships between different aspects of cognitive functioning with measures of the two fundamentally different aspects of mobility, i.e., capacity and performance, as defined by the World Health Organization. Our study specifically aims to analyze the strength of the

associations of different cognitive domains with mobility capacity and real-life mobility performance.

We hypothesize that cognitive functioning is more related to real-life mobility performance than to mobility capacity as measured with standardized laboratory tests. The study's results will add to our knowledge of the associations between cognition and mobility and thus may contribute to the institution of preventive measures to delay the transition to dependency and promote higher quality of life in old age.

Methods

This study was part of the 'Mobility study' of the German Sport University Cologne which aimed to analyze determinants of daily life mobility in older adults. All participants completed a laboratory-based test battery including several physical, cognitive, social and psychometric tests as well as an ambulatory mobility assessment. The local ethics committee approved the study protocol, which is in accordance with the declaration of Helsinki.

Participants

Community-dwelling participants were recruited by following strategies: (1) presentations of the project at local senior citizen gatherings, (2) individual invitation letters to persons who expressed interest in participating in studies of the Institute of Movement and Sport Gerontology in the past, and (3) handing out information brochures about the study and individual approach in settings such as local doctor's offices, pharmacies, churches, and senior sport groups. In order to increase the performance spectrum and therefore also representativeness of our sample, we also recruited participants from assisted living facilities by presenting our project during special events on-site. In total, 86 persons meeting the criteria for participation in the study were initially recruited. Inclusion criteria were: age older than 65 years, no serious neurological diseases which could interfere with functional mobility (e.g., Parkinson's disease, acute/severe stroke with high motor/sensory deficits and multiple sclerosis,) no cardiovascular diseases, no cognitive impairment, ability to stand up from a chair independently, a physician's written statement of non-objection for this person to participate confirming the absence of these exclusion criteria and informed consent to the study design.

Mobility measures

Mobility capacity was assessed in the laboratory using the extended, instrumented version (Salarian et al. 2010) of the

Timed Up-and-Go test (Podsiadlo and Richardson 1991). Besides the parameter ‘total duration’ for the completion of the test (iTUG), the execution of each of the tests sub-components was quantified using the data recorded by the six inertial measurement units (Opal, APDM Inc., Portland, OR, USA) attached to the participants’ bodies by calculating following variables (see Salarian et al. 2007; Salarian and Horak 2010; Salarian et al. 2004): sit-to-stand (StS) transition: peak velocity (degrees/s), range of motion of the trunk (ROM-Trunk) (degrees); Gait: stride length (m), stride velocity (m/s), cadence (steps/min); Turn: duration (s), peak velocity (degrees/s), number of steps (NOS); Turn-to-Sit (TtS) transition: peak velocity (degrees/s). Each participant completed three trials. The first trial was considered as practice, and the mean values from the second and third trial were used for analysis.

Mobility performance in real life was assessed over one week based on measuring motion-sensor and GPS data by means of smartphone technology. The detailed ambulatory mobility assessment strategy and data handling for the calculation of the used variables have been described elsewhere (Giannouli et al. 2016). In brief, from the motion-sensor data, the variable ‘Active- & Gait Time’ (AGT) was used, which is the sum of the durations (in hours) of active and gait intervals—as identified based on activity counts and metabolic equivalents (METs) (Sasaki et al. 2011) and a step detector (Ryu et al. 2013). From the GPS data following variables were used: ‘life-space’ (km²), the area within which the participants moved during the registration period; ‘Distance’ (km), the total distance travelled during the registration period; and ‘maximum action range’ (AR-max) (km), the largest straight-line distance away from the home location during the registration period.

Cognitive measures

The cognitive assessment included executive functioning measures which are necessary for both mobility capacity and mobility performance with special focus on visuospatial cognitive tasks, as they have been found to interfere with locomotor control to a greater extent than non-spatial tasks (Beurskens and Bock 2012; Cohen et al. 2016; Menant et al. 2014). More specifically, we measured planning, spatial working memory and visuospatial attention. To measure planning ability, two subtasks of the HOTAP picture-sorting test (Menzel-Begemann 2009) were used. For the first part of the test (HOTAP.A), which is based on the picture arrangement task of the Wechsler Adult Intelligence Scale, participants had to chronologically arrange pictures of everyday situations (e.g., shopping in a supermarket or refuel a car at a gas station) that were presented in a wrong order. For the second part of the test

(HOTAP.B), participants had to read a story and then arrange the pictures of situations presented in front of them according to the story. In both parts, every correctly rearranged picture granted one point. The outcome variables were the sum of the points divided by the time they needed to arrange the cards.

Participants’ spatial working memory was assessed via a simple and a complex Grid-Span task (Hale et al. 1996). In both tasks, participants had to remember the locations of a series of stimuli (X signs) that were presented sequentially in the nine cells of a grid, which remained on the screen throughout the series. The difference between the simple and the complex span task concerns stimuli reproduction. In the simple task (GSS), participants had to respond by marking those cells where stimuli had been presented. In the complex span task (GSC), they had to mark cells one position to the right of the one they had been presented. Outcome variable for both test versions was the maximum number of stimuli the participants could reproduce correctly (participants had three trials for every set of stimuli).

Visuospatial attention was assessed with the Attention Window test (Hüttermann et al. 2013). Participants fixated in the center of a screen while two sets of four different forms (light or dark gray triangles, squares, circles) were presented equidistantly from the fixation point along one of four axes (horizontal, vertical, diagonal) in different distances for 600 ms. Participants were then prompted to report the number of the light-gray triangles, first in one and then in the other set of forms. Responses were not measured in terms of speed. Outcome variables were the percentage of correct answers along all axes (AWT) as well as along the horizontal axis (AWH). Answers were considered correct only if the reported number was correct for both sets.

Statistical analyses

Data analysis consisted of four main phases: a multiple correlation approach to look into the overall relationships between all mobility and cognition parameters; a factor analytic approach for the mobility variables; a multiple correlation analysis between the cognitive variables and the resulting mobility factors and a multiple regression analysis. The principal component analysis (PCA) was conducted in order to establish underlying dimensions between different mobility parameters. Varimax rotation was used to derive orthogonal factor scores, applying the Kaiser’s eigenvalue-greater-than-one rule.

The scores of the resulting factors (which were computed using the regression method) as well as the cognitive measures were then used for another multiple correlation analysis to identify which mobility parameters best relate to cognition. Finally, a series of stepwise multiple

regression analyses in which the four factors resulting from the PCA served as dependent variables and the five cognitive measures (HOTAP.A, HOTAP.B, AWT, AWH, GSS, GSC) as predictors. For all analyses, the significance level was set at 0.05 except for the Kolmogorov–Smirnov test which was used to assess the normality of the datasets and for which the significance level was set at 0.10.

Results

Descriptive statistics

From the initial 86 participants, two were excluded from the analysis for not completing the ambulatory mobility assessment, 15 for not providing a complete GPS or motion-sensor dataset and three because of missing iTUG variables. The final sample, therefore, consisted of 66 persons. In these subjects, the mean real-life mobility registration period was 7.03 ± 1.64 days. Table 1 provides a description of the sample's demographics and also summarizes their cognitive and mobility measures.

Participants were primarily women. Men and women were similar in age. Twelve percent of the participants were living in assisted living facilities. Half of the participants were living alone and only 14% had a higher education degree. None of the participants was using gait assistance. In total, 74% of the participants reported health problems (42% were multimorbid and another 32% suffered from a single disease). The main reported health problems were: cardiovascular diseases (36% of the subjects), internal/endocrinological diseases (38%), orthopedic problems (39%), neurological/psychiatric diseases (11%) and others (2%). Regarding use of medication, 69% of the participants reported using medication (35% of the participants used multiple kinds of medication and 24% only one kind).

Overall correlation approach

The initial correlation approach between all mobility and cognitive measures revealed significant correlations mostly for the Attention Window test (between $r = .228$ and $r = .513$), and especially the AWH (between $r = .257$ and $r = .513$), which correlated significantly with 12 of the 14 mobility variables from all categories. HOTAP.A and HOTAP.B correlated significantly only with real-life mobility (between $r = .240$ and $r = .345$ and between $r = .241$ and $r = .258$, respectively) and gait parameters (between $r = .320$ and $r = .321$ and between $r = .241$ and $r = .326$, respectively). The Grid-Span tasks showed the least and weakest significant correlations (between

Table 1 Participants' descriptive data, cognitive measures and mobility measures

	Mean	SD	Min	Max
<i>Descriptive data</i>				
Age (total sample) (years)	72.3	5.6	65	88
Men ($n = 24$)	71.9	4.9	65	83
Women ($n = 42$)	72.6	6.0	64	88
BMI (kg/m^2)	23.7	3.2	16.7	33.1
<i>Cognitive measures</i>				
HOTAP.A	10.2	4.3	4.1	24.5
HOTAP.B	7.0	2.6	2.5	14.3
Attention Window (total)	70.4	23.5	5.7	95.0
Attention Window (horizontal)	69.7	22.6	3.4	96.6
Grid-Span (simple)	4.6	1.1	3.0	8.0
Grid-Span (complex)	3.8	0.9	3.0	6.0
<i>Real-life mobility measures</i>				
AGT (h)	4.3	0.9	1.8	6.1
Distance (km)	116.7	64.7	13.1	289.6
Life-space (km^2)	59.7	62.1	0.2	300.0
AR-max (km)	10.1	4.4	0.5	15.0
<i>iTUG measures</i>				
iTUG (s)	16.16	2.65	11.49	30.21
<i>Gait measures</i>				
Stride length (m)	1.41	0.12	1.06	1.62
Stride velocity (m/s)	1.39	0.16	0.82	1.77
Cadence (steps/m)	118.55	11.19	88.43	151.74
<i>Turn measures</i>				
Duration (s)	2.24	0.70	1.23	5.04
NOS (n)	4.97	1.36	2.00	9.50
Peak velocity (degrees/s)	171.7	38.5	91.0	296.9
<i>Sit-to-stand transition measures</i>				
ROM-Trunk (degrees)	35.4	7.2	20.3	53.2
Peak velocity (degrees/s)	117.8	46.5	68.1	349.2
<i>Turn-to-Sit transition measures</i>				
Peak velocity (degrees/s)	180.7	42.7	78.1	273.9

Mean average values, SD standard deviation, Min minimum values, Max maximum values, BMI body mass index, AGT active and gait time, AR-max maximum action range, iTUG instrumented Timed Up-and-Go test, NOS number of steps, ROM-Trunk range of motion of the trunk

$r = .205$ and $r = .308$). All bivariate correlations between cognitive and mobility measures are presented in Table 2.

Principal component analysis

All 14 mobility variables (as presented in Table 1) were included in the principal component analysis, which yielded five orthogonal factors accounting for 83.2% of total variance. However, the fifth factor included only one item

Table 2 Uncorrected correlation coefficients (Pearson's for the normal-distributed and Spearman for the not-normal-distributed datasets) r between all mobility measures and cognitive measures (* $p < .05$; ** $p < .01$)

	HOTAP.A	HOTAP.B	AWT	AWH	GSS	GSC
AGT	.192	.249*	.407**	.441**	-.045	.168
Distance	.240*	.258*	.319**	.360**	.075	.222*
Life-space	.345**	.241*	.315**	.412**	-.011	.183
AR-max	.292**	.185	.228*	.345**	-.001	.174
iTUG	-.320**	-.273*	-.256*	-.303**	-.182	-.198
Stride length	.321**	.241*	.149	.259*	.197	.157
Stride velocity	.321**	.326**	.273*	.303**	.202	.270*
Cadence	.110	.153	.171	.139	-.032	.104
Turn: duration	-.164	-.069	-.294**	-.353**	-.219*	-.106
Turn: NOS	-.078	.001	-.197	-.257*	-.205*	-.093
Turn: Peak velocity	.134	.112	.357**	.384**	.308**	.228*
StS: ROM-Trunk	.067	.132	.371**	.352**	.173	.285*
StS: Peak velocity	.108	.073	.167	.133	-.010	.156
Tts: Peak velocity	.181	.198	.483**	.513**	.214*	.241*

AWT Attention window total (along all axes), AWH Attention window horizontal, GSS Grid-Span simple, GSC Grid-Span complex, AGT active and gait time, AR-max maximum action range, iTUG instrumented Timed Up-and-Go test, Turn: NOS number of steps during the 180° turn, StS: ROM-Trunk range of motion of the trunk during the sit-to-stand transition, StS: Peak velocity peak velocity during the sit-to-stand transition, Tts: Peak velocity peak velocity during the Turn-to-Sit transition

Table 3 Item loadings for the Varimax-rotated solution

	Turn 1	Gait 2	Real-life mobility 3	Sit-to-stand transition 4
AGT	.259	.406	.484	.349
Life-space	.111	-.019	.879	-.150
Distance	.110	-.057	.864	.049
AR-max	-.019	.078	.854	.107
iTUG	-.335	-.812	-.129	-.124
Stride velocity	.197	.832	.049	.092
Cadence	.032	.918	-.128	.051
StS: ROM-Trunk	.135	.030	.016	.855
StS: Peak velocity	-.107	.141	.019	.867
Turn: Duration	-.924	-.257	-.042	.044
Turn: NOS	-.932	.120	-.008	.057
Turn: Peak velocity	.856	.258	.140	.086
Tts: Peak velocity	.594	.420	.266	.248
Explained variance (%)	35.7	16.8	14.0	9.5

AGT active and gait time, AR-max maximum action range, iTUG instrumented Timed Up-and-Go test, StS: ROM-Trunk range of motion of the trunk during the sit-to-stand transition, StS: Peak velocity peak velocity during the sit-to-stand transition, Turn: NOS number of steps during the 180° turn

(stride length) and since factors with fewer than three items loading on them are considered weak and unstable (Costello and Osborne 2005; Henson 2006), it was not considered in further analyses. The Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy (.657) and the Bartlett's test of Sphericity ($p = .000$) indicated that the underlying assumptions for factor analysis were met (Williams et al. 2012). The remaining four-factor structure is presented in Table 3: three factors represent iTUG-based

capacity data and one factor represents real-life mobility data with GPS-derived variables and little contribution of physical activity variables.

Correlation analysis

Table 4 illustrates that AW correlated significantly with most mobility parameters—as formed by the scores of the factor analysis, whereas both HOTAP tasks correlated with

Table 4 Uncorrected correlation coefficients (Pearson's for the normal-distributed and Spearman for the not-normal-distributed datasets) between factor scores and cognitive measures

	HOTAP.A	HOTAP.B	AWT	AWH	GSS	GSC
Turn	.028	.010	.282*	.316**	.210*	.056
Gait	.199	.237*	.179	.196	.027	.107
Real-life mobility	.274*	.229*	.322**	.396**	-.012	.175
Sit-to-stand transition	.114	.152	.315**	.271*	.086	.203

AWT Attention window total (along all axes), AWH Attention window horizontal, GSS Grid-Span simple, GGC Grid-Span complex

* $p < .05$; ** $p < .01$

Table 5 Predictors and their standardized regression coefficients for the mobility-related activity measures

Turn		Gait		Real-life mobility		Sit-to-stand transition	
Predictors	Beta	Predictors	Beta	Predictors	Beta	Predictors	Beta
AWH	.319**	AWH	.281*	AWH	.368**	AWT	.293*
$R^2 = .102^{**}$		$R^2 = .079^*$		$R^2 = .135^{**}$		$R^2 = .086^*$	
<i>Excluded variables</i>							
HOTAP.A	-.063	HOTAP.A	.132	HOTAP.A	.188	HOTAP.A	-.006
HOTAP.B	-.155	HOTAP.B	.143	HOTAP.B	.088	HOTAP.B	-.01
AWT	-.011	AWT	-.338	AWT	-.154	AWH	.022
GSS	.116	GSS	-.082	GSS	-.117	GSS	.009
GSC	-.06	GSC	.06	GSC	.008	GSC	.032

AWT Attention window total (along all axes), AWH Attention window horizontal, GSS Grid-Span simple, GGC Grid-Span complex

* $p < .05$; ** $p < .01$

real-life mobility measures and HOTAP.B additionally with *gait*. GSS correlated significantly only with *Turn* variables and the GSC did not correlate significantly with any of the mobility parameters.

Multiple regression analysis

To evaluate the predictive ability of cognition for each of the mobility parameters—as formed by the factor analysis—four stepwise multiple regression analyses were conducted. For the stepwise model, the limit was $F = 0.05$ for entry and $F = 0.10$ for removal of variables. The predictor variables were checked for multicollinearity, and all variance inflation factor values were equal to 1 indicating no multicollinearity among factors.

The Attention Window measures were the only significant predictors retained in the four models: AWH for the models 'Turn' ($R^2 = .102$, $p < .01$), 'Gait' ($R^2 = .079$, $p < .05$), and 'real-life mobility' ($R^2 = .135$, $p < .01$) and AWT for the 'sit-to-stand Transition' model ($R^2 = .086$, $p < .01$). Table 5 summarizes the results of the multiple regression analyses.

In order to explore the role of potential confounders for the relationship between mobility and cognition, another correlation analysis between age, gender, education, and health and the mobility parameters was applied. In our

dataset, there were no significant correlations between them besides education which correlated significantly with gait ($r = .311$) and after controlling for it, AWH remained the only marginally significant predictor in the regression model.

Discussion

The aim of this study was to investigate the relative contribution of different cognitive domains toward mobility capacity and real-life mobility performance.

A principle component analysis reduced our mobility measures to four orthogonal factors. 'Real-life mobility' was an independent factor from other mobility-related factors ('Turn,' 'Gait' and 'StS'). This is in line with previous research stating that mobility capacity and mobility performance constitute separate domains of physical function (Giannouli et al. 2016; van Lummel et al. 2015).

Similar to previous research, we found cognition to be associated with all aspects of mobility, namely, with physical activity (Buchman et al. 2008; Zhu et al. 2015), GPS-derived measures such as life-space (Tung et al. 2014) and action range (Tung et al. 2014; Wettstein et al. 2014b), gait (Buchman et al. 2011; Inzitari et al. 2007; Martin et al.

2013; Mielke et al. 2013), turn (Herman et al. 2014; Mirelman et al. 2014), sit-to-stand transitions (Herman et al. 2014; Mirelman et al. 2014) and mobility tests (Donoghue et al. 2012; Herman et al. 2011; Herman et al. 2014; McGough et al. 2011; Mirelman et al. 2014).

A specific pattern can be discerned in Table 4. Cognition had most significant associations with real-life mobility, fewer with ‘sit-to-stand’ and ‘turn’ and only one association with ‘gait.’ This is in line with the view that more complex activities require more complex cognitive contributions. Furthermore, spatially distributed attention had the most significant links to mobility, planning had fewer links and working memory had only one weak link, suggesting that mobility draws differently on different cognitive functions. The predominant role of visuospatial attention is in line with previous studies about the association between the useful field of view—a similar construct as our Attention Window and life-space (Sartori et al. 2012). It also is in accordance with studies reporting significant relationships between yaw amplitude during turns and attention (Herman et al. 2014) or visual-spatial ability (Mirelman et al. 2014). The small role of spatial working memory is in agreement with Wettstein et al. (2014b) but not with another study (Buchman et al. 2008); spatial working memory may play a minor role for mobility, or our Grid-Span test may not be sensitive enough to capture that role.

It might seem surprising that steady gait correlated little with cognition in the present study, given that earlier work found close associations, particularly with executive functioning (Martin et al. 2013; Mielke et al. 2013), working memory (Buchman et al. 2011) and attention (Inzitari et al. 2007; Martin et al. 2013). However, our preliminary correlation analysis did yield significant correlations of both gait variables with all cognitive measures (see Table 2), which indicates that correlations reported in the literature were present in our data as well, but were masked by more predominant effects in our analysis.

To sum up, we found cognition to correlate more closely with performance than with capacity, in accordance with our hypothesis. Visuospatial attention was the most predominant predictor of mobility, which is in line with previous research showing significant relationships between attention and several aspects of mobility such as overall motor performance (Inzitari et al. 2007), mobility (Owsley and McGwin 2004) and stair descent performance (Telonio et al. 2014). Hence, it is likely that attention training also has a positive effect on motor performance. Indeed, the study of Li et al. (2010) found transfer effects of non-motor attention training on balance ability. Further studies should examine the effects of attention training on additional aspects of mobility, for example gait but also out-of-home mobility.

Although this study has the strength of examining the relationships between cognitive functioning and a wide range of mobility parameters, we acknowledge several limitations. First of all, the cross-sectional design does not allow causal conclusions. Secondly, we could have included other or additional measures of mobility and cognition in our study. Our cognitive measures were limited to only three domains, and our mobility assessment was based on typical laboratory measures in combination with general mobility measures obtained in real life. It would have been interesting to also include real-life gait measures. However, at present it still is a methodological challenge to obtain reliable measures of gait during unstandardized real-life conditions. Thirdly, our statistical analysis was suboptimal. Data loss resulted in a smaller sample size than planned and statistical significance might be inflated by the use of multiple statistical tests. In fact, Bonferroni–Holm adjustments for multiple testing reduced significance to only one single association, that between real-life mobility and AWH. Thus, Bonferroni–Holm adjustments actually highlighted the main outcome of the study, namely the close link between attention and real-life mobility.

Further studies should aim to monitor the same measures of mobility in the laboratory and in real-life, e.g., gait speed and examine the relationship between mobility and more/other cognitive domains longitudinally, focusing especially on the role of attention by assessing the attentional demands of mobility-related activities which are crucial for mastering activities of daily living in old age.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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