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Intraindividual variability and falls in older adults

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Running head: Intraindividual variability and falls

Abstract

Objective: We investigated whether a simple measure of reaction time intraindividual variability (IIV) was associated with falls in older adults. Falls and fall-related injuries represent a major cost to health care systems, it is therefore critically important to find measures that can readily identify older adults at greater risk of falling.

Method: Cognitive and motor function were investigated in 108 adults aged 53 to 93 years (*M* = 73.49) recruited across the local community and hospital outpatient department. Forty-two participants had experienced either an injurious fall, or multiple falls, in the previous two years.

Results: Logistic regression suggested that fallers could be distinguished from non-fallers by greater medication use, IIV, postural sway, weaker grip strength and slower gait speed. Structural equation models revealed that IIV was predictive of falls via the mediating variable of motor function (e.g., gait). IIV also predicted higher-order cognition (executive function) but higher-order cognitive function did not uniquely predict falls or account for the associations between IIV and falls.

Conclusions: These findings indicate that IIV measures capture important aspects of cognitive and motor decline and may have considerable potential in identifying older adults at risk of falling in healthcare and community settings.

Key words: cognition, intraindividual variability, motor control, fall, aging

Introduction

Aging populations around the world present a variety of challenges to healthcare systems in both developed and developing countries. One of the major challenges relates to falls in older adults. Falls represent a major cost to healthcare systems, and the frequently sustained subsequent injuries limit both quality of life and independence in old age. With 30% of people older than 65 years and 50% of people older than 80 years falling at least once a year, falls are estimated to cost the UK National Health Service more than £2.3 billion each year (NICE, 2013). It would therefore be useful to identify individuals at greater risk of falling before an adverse event so that appropriate advice and support can be provided.

In the present study we wished to examine the ability of 'cognitive' and 'motor' measures to identify fallers. We were interested in these factors as both cognitive decline and motor impairment have been linked to greater fall risk. It is well established that higher-order cognitive deficits (e.g., impaired 'executive control') are related to falls in old age (for reviews, see Beauchet et al., 2009; Kearney, Harwood, Gladman, Lincoln, & Masud, 2013). For example, the time to complete the 'Trail making B' executive control task was significantly slower in multiple fallers compared to non-multiple fallers (Pijnappels, Delbaere, Sturnieks, & Lord, 2010). Likewise, deficits in 'go-no-go' and Stroop tasks were found in participants reporting a fall during a two-year follow-up period (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010). There is also evidence that motor coordination difficulties relate to an greater risk of falling (Horak, 1997). Poor grip strength has not only been associated with dementia (e.g., Alencar, Dias, Figueiredo, & Dias, 2012) but also with falls (Campbell, Borrie, & Spears, 1989; Nevitt, Cummings, & Hudes, 1991; Pijnappels et al., 2010; Tromp et al., 2001). Impaired balance is also related to falls (Lord et al., 1994; Sturnieks et al., 2004) and it is likely that cognitive and motor deficits interact with regard to the risk of falling. Furthermore, the control of gait and posture shifts from sub-cortical pathways to cortical networks in conditions such as Parkinson's disease (Morris, Iansek, Matyas, & Summers, 1996). A decline in motor function because of old age can lead to a variety of compensatory behaviors (Holt et al., 2013; Raw, Kountouriotis, Mon-Williams, & Wilkie, 2012) that may be strategic, explicit and under conscious cognitive control. Indeed, in dual-task conditions (e.g., speaking while walking) older adults may not reallocate resources appropriately and therefore fail to compensate adequately (Harley, Wilkie, & Wann, 2009). In support of the idea that motor and cognitive factors interact in falls risk, dual-task performance has been found to decline in individuals who have experienced a first fall over a 12-month period (Verghese et al., 2002).

The fact that cognitive and motor factors predict risk of falling suggests that it would be useful to measure cognition and motor performance in older adults. The problem is that tests for cognitive and motor performance tend to be time consuming and rely on relatively expensive apparatus and trained professionals (e.g., neuropsychologists and occupational therapists). We were therefore interested in exploring whether a relatively fast and easy-to-administer composite measure of cognitive and motor status might provide a useful measure of an individual's risk of falling. Our goal was to determine whether intraindividual variability (IIV) might provide a useful measure that could indicate individuals at risk of falling. IIV is commonly operationalized through the trial-to-trial variation in reaction times (RTs) for a given cognitive task and thus has both cognitive and motor components. Theoretically, this measure is thought to capture moment-to-moment fluctuations in attentional or executive control mechanisms (Bunce, MacDonald, & Hultsch, 2004; Bunce, Warr, & Cochrane, 1993; West, Murphy, Armilio, Craik, & Stuss, 2002) and so is considered a useful marker of neurobiological disturbance (e.g., Hultsch, 2008). IIV has been the subject of considerable interest within the aging literature, as not only does it increase with age (e.g., Bielak, Hultsch, Strauss, Macdonald, & Hunter, 2010; Hultsch, MacDonald, & Dixon, 2002) but it is also predictive of a variety of neuropathological conditions including mild cognitive impairment (e.g., Bielak et al., 2010; Christensen et al., 2005) dementia (e.g., Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Murtha, Cismaru, Waechter, & Chertkow, 2002) and Parkinson's disease (de Frias, Dixon, Fisher, & Camicioli, 2007). It has also been suggested that greater variability is associated with gait impairment and falls in old age (for a review, see Graveson, Bauermeister, McKeown, & Bunce, 2015). Together, this body of work suggests that IIV is not only sensitive to aging and age-related neuropathological disturbance but, importantly, is also predictive of older adults at risk of gait impairment and falling. The measure may, therefore, have potential for screening and assessment in clinical contexts.

In summary, we hypothesized that IIV (captured through moment-to-moment changes in keypress reaction-times within cognitive tasks) may be related to falls. We tested this hypothesis using logistic regression analyses and structural equation modelling in a sample of older adults recruited from the community and the health service.

Methods

Participants

One hundred and eight (78 women) persons aged 53 to 93 years (*M* = 73.49; *SD* = 8.79) were recruited from the local community and the UK National Health Service (NHS). Of the 108 participants, 42 self-reported an injurious fall, or multiple falls, in the preceding 24 months. In order to address possible dementia, the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was administered and all participants scored ≥26. Full-scale IQ was estimated using the National Adult Reading Test (Nelson, 1982). We screened for gross visual deficits using a Snellen chart placed at 3m. We also measured visual contrast using the Melbourne Edge Test following standard procedures (MET; Verbaken, 1986). The study received ethical approval from appropriate university and NHS research ethics committees.

Falls History

A fall was defined as “an unexpected event in which the person comes to rest on the ground, floor, or lower level” (Lamb et al., 2005). Following procedures elsewhere (Delbaere et al., 2010; Delbaere et al., 2012), “Fallers” were identified as having one injurious fall or multiple non-injurious falls in the previous 24 months.

IIV Measures

Reaction times were collected across a battery of cognitive tasks using E-Prime (Psychology Software Tools, 2012) software. Practice trials were administered throughout and test trials were presented pseudo-randomly. Correct trials only were used in statistical analyses. In a

Simple RT task (SRT) over 48-trials, participants pressed the space bar whenever an ‘X’ appeared in the center of the computer screen. Inter-trial intervals were randomised between 300 and 1,000 ms. In a *Two-Choice version* of the task (2-CRT), participants responded to a black 25 mm diameter circle presented either to the right or the left of the screen using designated keyboard keys, left or right. Here, the inter-trial interval was 500 ms. A 64-trial *simple visual search* task was also administered where a 6 x 6 array of green letter ‘O’s was presented. For 32 of the trials, a green target letter ‘Q’ was embedded randomly within the array. Designated keyboard keys were pressed to indicate the presence or absence of the Q. The inter-trial interval was 500ms. Two further RT tasks emphasized inhibitory control. First, a 64-trial version of the Eriksen *Flanker* task (Eriksen & Schultz, 1979) was presented in which participants responded to the horizontal direction of a central target arrow while ignoring the distractor flanker arrows (2 either side of the target arrow) using designated keyboard keys, left or right. The trials were divided equally into congruent (arrows pointing in same direction) and incongruent (middle arrow pointing in the opposite direction to the flanker arrows) trials. Inter-trial intervals were randomised between 300 and 1000 ms. Second, in a 96-trial *Stroop word* task, participants responded to the presented word ink color (red, blue, yellow or green) and ignored the written word (“red”, “blue”, “yellow” or “green”) using four appropriately colored keys. The trials were equally divided into congruent (word-color match) and incongruent (word-color mismatch) trials. The inter-trial interval was 500ms. For the RT tasks, data were trimmed by eliminating extremely fast or slow trials using a lower boundary of 150ms and an upper boundary of the individual mean RT + 3 individual *SD*s. A minority of error trials were also excluded. Eliminated trials were replaced with the individual’s mean RT for that task. The within-person coefficient of variation ($CV = SD/M$) was used as a measure of IIV in all statistical analyses. We chose this measure of variability as it takes mean RT into account thereby controlling for age-related slowing. Work from our own group (Bunce et al., 2013) and elsewhere (Lovden, Li, Shing, & Lindenberger, 2007), suggests the CV provides similar findings to other measures of IIV.

Higher-order cognitive measures

Higher-order cognition ('executive function') was measured using paper-and-pencil tasks. The *Trail making A and B* tasks (TMT; Army Individual Test Battery, 1944) were administered. In the TMT-A participants were required to sequentially join 25 numbered dots (1-2-3-4-5-6…..etc.) as quickly and accurately as possible. The time taken to join the dots was recorded. In the TMT-B version of the task, participants were required to sequentially join 12 numbered and 12 lettered dots, alternating between number and letter (1-A-2-B-3-C…..etc.). Again, time taken to join the dots was recorded. To test *Verbal fluency (and executive control)* an Alternate Category Task (Parkin, Walter, & Hunkin, 1995) was administered requiring the alternating generation of unique animal and country names in a one minute period. A correct score was recorded for each successful animal-country switch. Executive function was additionally measured using the computed difference between TMT-B and A (TMT-costs).

Motor measures

Grip strength: Grip strength was measured using a Smedley digital hand dynamometer (Model: 12-0286, Baseline® Evaluation Instruments) which measured force exerted in kg. Six trials were administered alternating right and left hands and the mean average force (kg) was computed (Roberts et al., 2011). *Gait speed:* Gait speed was timed over a 4-meter measured distance where participants were instructed to walk their 'normal walking pace' along a track. Three trials were administered and the mean average time was computed (Studenski et al., 2011). *Leg resistance:* Leg resistance was measured using a custom-made, adjustable Velcro™

leg strap attached to a portable digital hanging scale (NOPS® Model: 30890, 200kg capacity). The strap was fastened to the back leg of an upright, stable chair. The strap was placed around the participant's preferred leg, approximately 10 cm above the ankle (Lord, Menz, & Tiedemann, 2003). Participants were instructed to pull firmly against the strap in a knee extensor movement using minimal lift. Three trials were administered with the same leg and the mean average resistance (kg) was computed. *Balance:* Postural sway was measured using a Nintendo Wii-Fit™ balance board. Participants were instructed to stand upright on the board with their feet placed inside taped markings, a shoulder-width apart. Data were collected on a Toshiba laptop through a customised postural sway program (Flatters, Culmer, Holt, Wilkie, & Mon-Williams, 2014) using LabVIEW (National Instruments) script. Participants were required to stand as still as possible for 30 seconds with their eyes open while the Wii board monitored the center of pressure (COP) at 60 Hz. From this, a COP deviation was estimated.

Procedure

The test session commenced with a comprehensive biographical questionnaire, falls history, MMSE and NART. These were followed by measures of grip strength, leg resistance, eyesight and gait speed. The cognitive measures were then administered, followed by the balance measures. The testing session lasted approximately one hour.

Statistical analyses

The main analyses involved, first, individual logistic regression analyses to identify the strongest predictors of falls. Second, a 2-step multiple-mediation analysis involving all key variables was conducted using structural equation modelling. In Step 1, a direct path model was used with falls as the outcome variable and IIV as the predictor. In Step 2, falls was the outcome variable, IIV was the predictor variable, and executive and motor function served as mediating latent variables (see Figures 1 and 2).

Results

Descriptive statistics for non-fallers and fallers are presented in Table 1. Fallers were significantly older and recorded lower NART scores (ranges: Non-fallers 104-128; Fallers 100-128). Therefore, age and NART scores were taken into account in all subsequent multivariate statistical procedures. There were significant between-group differences for the majority of IIV, executive function and motor measures with fallers exhibiting deficits across all variables. For the RT tasks, fallers were more error prone than non-fallers[1]. Percentages of inaccurate trials for non-fallers and fallers, respectively were 2-CRT 1.6 to 4.15; Flanker 5.8 to 17.5; Stroop 4.8 to 8.1; Visual search 5.2 to 6.1.

Table 2 presents logistic regression analyses after adjusting for age and additionally for NART scores in the IIV and executive function analyses. Falls (1 = yes, 0 = no) were regressed onto all of the function variables in individual logistic regressions. For the demographic and health variables, more medications and poor general health score were significantly associated with falling (all *p*s <.01). For the motor measures, poorer balance, slower gait speed and weaker grip strength were all significantly associated with the prevalence of falls (all *p*s <.01). Regarding the IIV measures, greater variability in the 2-CRT, flanker and Stroop word tasks was significantly associated with a higher likelihood of

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[1] For descriptive purposes and in order to provisionally explore associations between the main variables, we computed bivariate correlations. For interested readers, this table is posted as supplementary material online.

falls (all *p*s < .05)[2]. Lower verbal fluency scores also predicted falls, suggesting that poorer executive control was associated with a greater prevalence of falls (*p* < .01).

The relationship between falls, age, IIV, executive function and motor measures was then investigated using structural equation modelling. For these analyses we used a 2-step multiple mediator model (Holbert & Stephenson, 2010; Preacher & Hayes, 2008) that allowed multiple explanatory variables of the IIV-falls association to be assessed simultaneously. Latent constructs were computed from the variables which were significant in the logistic regression analyses. Thus, a latent 'motor' construct was computed from gait speed, grip strength and balance measures, while an IIV latent variable was constructed from the 2-CRT, flanker and Stroop tasks. For executive function, TMT-costs and verbal fluency measures were used to form the latent construct[3]. We adjusted for age and NART scores in all of the models.

Model 1 assessed the initial relationship between IIV and falls (see Figure 1). The direct standardized regression path (Path a in Figure 1) was assessed and this was significant, suggesting a direct effect of IIV on falls. This is consistent with the earlier logistic regression analyses where greater IIV was associated with a greater likelihood of falling (Table 2). Model fit statistics suggested acceptable fit (Kenny, 2014; Kline, 2010). A second model was then generated in order to evaluate whether this effect was mediated by another variable (Figure 2). This multiple mediator model assessed the separate direct regression paths from IIV to

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[2] We repeated these analyses adding percentage correct for the respective task to the models as it may be of interest to some readers, whether accuracy or CV was the stronger predictor of falls. Here, the CV for 2-CRT remained significant while those for the Flanker (*p* = .058) and Stroop (*p* > .27) tasks became nonsignificant. When entered alone into the models, percentage correct failed to significantly predict falls.

[3] Because two variables are required to construct the latent variable, TMT-costs were included even though this variable did not reach significance in the logistic regression.

executive or motor function (Paths b and c, respectively), as well as the direct paths from executive and motor function to falls (Paths d and e, respectively). Executive and motor function are thereby placed as mediating variables within the model, creating indirect mediation paths: IIV → Executive function → Falls (Path f) and IIV → Motor Function → Falls (Path g). To compute the mediation effect and interpret the multiple mediator model, the direct unstandardized regression paths within each indirect path were used (Holbert & Stephenson, 2010; Preacher & Hayes, 2008). These beta weights were converted to z-scores and the mediation path was the product of these two z-scores. The significance level of the z-score product was determined relative to the x,y normal distribution (Craig, 1936). The rationale was that if the direct path between IIV and Falls (Path a) became nonsignificant while the indirect mediator paths attained significance, it would be reasonable to conclude that full mediation has occurred (Baron & Kenny, 1986). If the direct path between IIV and Falls remained significant while the indirect path was significant, then partial mediation has occurred.

In Model 2 (see Figure 2), model fit statistics suggested acceptable fit (Kenny, 2014; Kline, 2010). Importantly though, the direct path between IIV and Falls (Path a) that was significant in Model 1, became nonsignificant thereby fulfilling one of the criteria for mediation (Baron & Kenny, 1986). Additionally, although the direct standardised Executive Function to Falls path (Path d) was nonsignificant, all of the other direct paths (Paths b, c, e) were significant suggesting direct effects between these latter variables. Critically, the outer pathway representing the indirect effect of the mediator, was nonsignificant for IIV → Executive Function → Falls (Path f) but significant for IIV → Motor Function → Falls (Path g). This suggests that Motor Function, rather than Executive Function, mediated the association between IIV and Falls.

In order to better understand the influence of Motor Function, a further series of logistic regression models were run. These models investigated the mediating effect of the individual Motor Function components (gait speed, grip strength or balance) on the IIV-Falls association. In Model 1, falls were regressed on IIV adjusting for age and NART. This model was then re-run but systematically adjusting for either gait speed, grip strength or balance. The key element in these repeated analyses was whether the beta values from the IIV-Falls association in the first analysis became non-significant or were attenuated. The outcome of this analysis was that in Model 1, the beta value for IIV was significant ($\beta = 1.10$, $p <.01$). When the model was subsequently adjusted for either Sway, Grip strength or Gait speed, although IIV remained significant for each component of motor Function, the beta value was attenuated for Gait Speed ($\beta = .87$, $p <.05$) and more marginally for Grip Strength ($\beta = 1.05$, $p <.01$). For Balance, the beta value marginally increased but dropped in significance level ($\beta = 1.20$, $p <.05$). This analysis informs the earlier structural equation models as it suggests that Gait speed and to a lesser extent, Grip strength were influential in the mediation effect found for the IIV-Falls association.

Discussion

This study set out to provide insights into the relationship between IIV, higher-order cognition (‘executive function’) and motor factors that influence falling in old age. The study was motivated by a body of evidence suggesting that cognitive and motor decline contribute (probably in an interactive manner) to an individual’s risk of falling. We were particularly interested in discovering whether relatively easy-to-administer tests of IIV might index decline in the cognitive and/or motor abilities that relate to risk of falling. There were two important findings. First, logistic regression analyses suggested that greater IIV (as measured by intraindividual reaction time variations) as well as deficits in executive and motor function were all associated with a higher likelihood of falling in this older sample. Second, structural equation modelling (that simultaneously took into account multiple sources of variance) revealed that the motor but not the executive function measures accounted for the association between IIV and falling.

The finding that measures of IIV predicted falls is consistent with empirical work elsewhere (Graveson et al., 2015). However, structural equation modelling indicated that it was the motor function rather than the higher-order cognition that accounted for that association. The relationship between motor function and falls is consistent with research that shows an association between gait and falls (for a review, see Ambrose, Paul, & Hausdorff, 2013), and grip strength and falls (Campbell et al., 1989; Nevitt et al., 1991; Pijnappels et al., 2010; Tromp et al., 2001). Nevertheless, the motor system does not operate in isolation from the cognitive system and there is good evidence to suggest that cognitive deficits increase risk of falling. It is likely that cognitive decline decreases the resources available to compensate for decrements in automatic motor processes, which would explain the relationship between dual-task performance and balance. It follows that in neuropsychological contexts, a measure that can capture a decline in cognition and motor function (e.g., IIV) might be extremely useful in identifying ‘at risk’ individuals and this is what the present research indicates.

It is of interest to note that the IIV measure was able to predict higher-level cognitive function (on tasks designed to operationalize cognitive skills that can be labelled as ‘executive function'). This indicates that the IIV measure did capture important components of cognition. Nevertheless, there was no direct pathway found between executive function and falling and neither did executive control mediate the IIV-Falls association. This finding was unexpected as work elsewhere (Kearney et al., 2013) suggests an association between executive function and falls. Following this evidence, we designed the study to include executive function as a potential mediator of associations with falls. However, as detailed in the Introduction, IIV theoretically captures fluctuations in executive control and as such, there is considerable conceptual overlap between the respective measures. Therefore, following Miyake's conceptual framework for executive function (Miyake et al., 2000), we based our IIV measure on the inhibition construct (Stroop and Flanker tasks) while the mediator variable captured the updating and switching constructs (verbal fluency and Trailmaking tasks). However, despite seeking to delineate between the key components of executive function in this way, it is possible that the lack of mediation effect for higher cognition was due to residual conceptual overlap between IIV and executive control measures. Clearly further work is required to disentangle linkages between these constructs in more detail. Additionally, higher-order cognitive functions by definition play a relatively minor role in lower-level perceptual-motor behaviors. This is not to suggest that higher-order cognition has no influence on an individual's risk of falling. The individual who fails to recognise the risks involved in going for a walk along an icy pavement or who fails to plan a route with good footing is more likely to experience a fall than someone with superior decision making abilities. But the present study did not involve individuals with gross impairment of higher-order cognition and it seems reasonable to assume that it is perceptual-motor capability and 'on-line' cognitive function which are the primary determinants of falls within such populations. Moreover, despite drawing on higher-order cognitive processes, measures of RT variability have a substantial motor component, and the findings suggest that in the present falls context, this may be particularly influential. In order to confirm and extend the present findings, it is important that both experimental and longitudinal population-based research identifies and elucidates the precise cognitive and motor mechanisms that underlie falls in old age.

Although the present study has a number of strengths including the community-based sample and use of advanced statistical procedures to investigate relations between key variables, there are some limitations we should acknowledge. First, as our study was cross-sectional, it was not possible to demonstrate the causal structure of the influences on falls. Second, fallers were significantly older and reported poorer general health and recorded more medication usage than non-fallers. Third, non-fallers tended to be more prone to errors on the RT tasks, which may have affected computations of the CV. Additionally, the measure of falls was retrospective and it is important that future research uses this measure prospectively. However, it seems unlikely that the falls precipitated IIV per se, suggesting that this measure is providing a potentially useful marker of risk. Moreover, the work has identified an extremely promising measure that could be usefully deployed in clinical settings and large scale epidemiological studies. It should be noted that measures of IIV are relatively quick and easy to administer, require little neuropsychological training, and can be constructed using minimal linguistic content. The present research demonstrates the ease with which these measures can be deployed within clinical settings. In contrast, the comprehensive battery of cognitive and motor tests used within the present research needed to be administered by a trained psychologist, used relatively expensive equipment and were time consuming to administer. Moreover, the clinics needed to make considerable adaptations in order for us to undertake the full cognitive and motor testing battery. Thus, IIV measures may have considerable potential for screening and assessment purposes in older and linguistically diverse populations. Given the present findings, and work showing IIV measures predict a range of age-related neurodegenerative disorders including mild cognitive impairment (e.g., Bielak et al., 2010), dementia (e.g., Hultsch et al., 2000) and Parkinson's disease (e.g., de Frias et al., 2007), it seems highly worthwhile to test these measures further in neuropsychological and more broadly in clinical contexts.

To conclude, the present findings suggest that IIV is associated with falls in old age. In light of the economic healthcare costs of falls in older populations (and costs in terms of restricted independence and diminished quality of life) there is a pressing need for early identification of older persons at risk of falling. The present findings suggest that measures of IIV may have considerable potential in this respect.

Conflict of interest

None

References

Alencar, M. A., Dias, J. M., Figueiredo, L. C., & Dias, R. C. (2012). Handgrip strength in elderly with dementia: study of reliability. *Rev Bras Fisioter, 16*(6), 510-514.

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: a review of the literature. *Maturitas, 75*(1), 51-61. doi: 10.1016/j.maturitas.2013.02.009

Baron, R. M., & Kenny, D. A. (1986). The moderator-mediator variable distiniction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*, 1173-1182.

Beauchet, O., Annweiler, C., Dubost, V., Allali, G., Kressig, R. W., Bridenbaugh, S., . . . Herrmann, F. R. (2009). Stops walking when talking: a predictor of falls in older adults? *Eur J Neurol, 16*(7), 786-795. doi: 10.1111/j.1468-1331.2009.02612.x

Bielak, A. A., Hultsch, D. F., Strauss, E., Macdonald, S. W., & Hunter, M. A. (2010). Intraindividual variability in reaction time predicts cognitive outcomes 5 years later. *Neuropsychology, 24*(6), 731-741. doi: 10.1037/a0019802

Bunce, D., Bielak, A. A., Cherbuin, N., Batterham, P. J., Wen, W., Sachdev, P., & Anstey, K. J. (2013). Utility of intraindividual reaction time variability to predict white matter hyperintensities: a potential assessment tool for clinical contexts? *J Int Neuropsychol Soc, 19*(9), 971-976. doi: 10.1017/S1355617713000830

Bunce, D., MacDonald, S. W., & Hultsch, D. F. (2004). Inconsistency in serial choice decision and motor reaction times dissociate in younger and older adults. *Brain Cogn, 56*(3), 320-327. doi: 10.1016/j.bandc.2004.08.006

Bunce, D., Warr, P. B., & Cochrane, T. (1993). Blocks in choice responding as a function of age and physical fitness. *Psychol Aging, 8*, 26-33.

Campbell, A. J., Borrie, M. J., & Spears, G. F. (1989). Risk factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol, 44*(4), M112-117.

Christensen, H., Dear, K. B., Anstey, K. J., Parslow, R. A., Sachdev, P., & Jorm, A. F. (2005). Within-occasion intraindividual variability and preclinical diagnostic status: is intraindividual variability an indicator of mild cognitive impairment? *Neuropsychology, 19*(3), 309-317. doi: 10.1037/0894-4105.19.3.309

Craig, C. C. (1936). On the frequency function of xy. *The Annals of Mathematical Statistics, 7*(1), 1-15.

de Frias, C. M., Dixon, R. A., Fisher, N., & Camicioli, R. (2007). Intraindividual variability in neurocognitive speed: a comparison of Parkinson's disease and normal older adults. *Neuropsychologia, 45*(11), 2499-2507. doi: 10.1016/j.neuropsychologia.2007.03.022

Delbaere, K., Close, J. C., Heim, J., Sachdev, P. S., Brodaty, H., Slavin, M. J., . . . Lord, S. R. (2010). A multifactorial approach to understanding fall risk in older people. *J Am Geriatr Soc, 58*(9), 1679-1685. doi: 10.1111/j.1532-5415.2010.03017.x

Delbaere, K., Kochan, N. A., Close, J. C., Menant, J. C., Sturnieks, D. L., Brodaty, H., . . . Lord, S. R. (2012). Mild cognitive impairment as a predictor of falls in community-dwelling older people. *Am J Geriatr Psychiatry, 20*(10), 845-853. doi: 10.1097/JGP.0b013e31824afbc4

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: a continuous flow conception and experimental results. *Percept Psychophys, 25*(4), 249-263.

Flatters, I., Culmer, P., Holt, R. J., Wilkie, R. M., & Mon-Williams, M. (2014). A new tool for assessing head movements and postural sway in children. *Behav Res Methods, 46*(4), 950-959. doi: 10.3758/s13428-013-0419-x

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Graveson, J., Bauermeister, S., McKeown, D., & Bunce, D. (2015). Intraindividual Reaction Time Variability, Falls, and Gait in Old Age: A Systematic Review. *J Gerontol B Psychol Sci Soc Sci*. doi: 10.1093/geronb/gbv027

Harley, C., Wilkie, R. M., & Wann, J. P. (2009). Stepping over obstacles: attention demands and aging. *Gait Posture, 29*(3), 428-432. doi: 10.1016/j.gaitpost.2008.10.063

Herman, T., Mirelman, A., Giladi, N., Schweiger, A., & Hausdorff, J. M. (2010). Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. *J Gerontol A Biol Sci Med Sci, 65*(10), 1086-1092. doi: 10.1093/gerona/glq077

Holbert, R. L., & Stephenson, M. T. (2010). The importance of indrect effects in media effects research: Testing for mediation in structural equation modeling. *Journal of Broadcasting and Electronic Media, 47*(4), 556-572. doi: 10.1207/s15506878jobem4704_5

Holt, R. J., Lefevre, A. S., Flatters, I. J., Culmer, P., Wilkie, R. M., Henson, B. W., . . . Mon-Williams, M. (2013). Grasping the changes seen in older adults when reaching for objects of varied texture. *PLoS One, 8*(7), e69040. doi: 10.1371/journal.pone.0069040

Horak, F. B. (1997). Clinical assessment of balance disorders. *Gait & Posture, 6*(1), 76-84.

Hultsch, D. F. (2008). Intraindividual variability, cognition and ageing In F. I. Craik & T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 491-556). New York: Psychology Press.

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *J Gerontol B Psychol Sci Soc Sci, 57*(2), P101-115.

Hultsch, D. F., MacDonald, S. W., Hunter, M. A., Levy-Bencheton, J., & Strauss, E. (2000). Intraindividual variability in cognitive performance in older adults: comparison of adults with mild dementia, adults with arthritis, and healthy adults. *Neuropsychology, 14*(4), 588-598.

Kearney, F. C., Harwood, R. H., Gladman, J. R., Lincoln, N., & Masud, T. (2013). The relationship between executive function and falls and gait abnormalities in older adults: a systematic review. *Dement Geriatr Cogn Disord, 36*(1-2), 20-35. doi: 10.1159/000350031

Kenny, D. A. (2014). Measuring Model Fit. Retrieved 15th July, 2015, from www.http://davidakenny.net/cm.fit.htm

Kline, R. B. (2010). *Principles and Practice of Structural Equation Modeling* (3rd Edition ed.). New York, USA: The Guildford Press.

Lamb, S. E., Jorstad-Stein, E. C., Hauer, K., Becker, C., Prevention of Falls Network, E., & Outcomes Consensus, G. (2005). Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. *J Am Geriatr Soc, 53*(9), 1618-1622. doi: 10.1111/j.1532-5415.2005.53455.x

Lord, S. R., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls risk assessment and prevention. *Phys Ther, 83*(3), 237-252.

Lord, S. R., Sambrook, P. N., Gilbert, C., Kelly, P. J., Nguyen, T., Webster, I. W., & Eisman, J. A. (1994). Postural stability, falls and fractures in the elderly: results from the Dubbo Osteoporosis Epidemiology Study. *Med J Aust, 160*(11), 684-685, 688-691.

Lovden, M., Li, S. C., Shing, Y. L., & Lindenberger, U. (2007). Within-person trial-to-trial variability precedes and predicts cognitive decline in old and very old age: longitudinal data from the Berlin Aging Study. *Neuropsychologia, 45*(12), 2827-2838. doi: 10.1016/j.neuropsychologia.2007.05.005

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cogn Psychol, 41*(1), 49-100. doi: 10.1006/cogp.1999.0734

Morris, M. E., Iansek, R., Matyas, T. A., & Summers, J. J. (1996). Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. *Brain, 119 (Pt 2)*, 551-568.

Murtha, S., Cismaru, R., Waechter, R., & Chertkow, H. (2002). Increased variability accompanies frontal lobe damage in dementia. *J Int Neuropsychol Soc, 8*(3), 360-372.

Nelson, H. (1982). *The National Adult Reading Test (NART)*. Windsor, England: Nfer-Nelson.

Nevitt, M. C., Cummings, S. R., & Hudes, E. S. (1991). Risk factors for injurious falls: a prospective study. *J Gerontol, 46*(5), M164-170.

NICE. (2013). Clinical guideline 161, Falls: assessment and prevention of falls in older people *National Institute for Health and Care Excellence Clinical Guideline 161*.

Parkin, A. J., Walter, B. M., & Hunkin, N. M. (1995). Relationships between normal aging, frontal lobe function, and memory for temporal and spatial information. *Neuropsychology, 9*, 304-312.

Pijnappels, M., Delbaere, K., Sturnieks, D. L., & Lord, S. R. (2010). The association between choice stepping reaction time and falls in older adults--a path analysis model. *Age Ageing, 39*(1), 99-104. doi: 10.1093/ageing/afp200

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing ad comparing indrect effects in multiple mediator models. *Behaviour Research Methods, 40*(3), 879-891. doi: 10.3758/BRM.40.3.879

Raw, R. K., Kountouriotis, G. K., Mon-Williams, M., & Wilkie, R. M. (2012). Movement control in older adults: does old age mean middle of the road? *J Exp Psychol Hum Percept Perform, 38*(3), 735-745. doi: 10.1037/a0026568

Roberts, H. C., Denison, H. J., Martin, H. J., Patel, H. P., Syddall, H., Cooper, C., & Sayer, A. A. (2011). A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. *Age Ageing, 40*(4), 423-429. doi: 10.1093/ageing/afr051

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., . . . Guralnik, J. (2011). Gait speed and survival in older adults. *JAMA, 305*(1), 50-58. doi: 10.1001/jama.2010.1923

Sturnieks, D. L., Tiedemann, A., Chapman, K., Munro, B., Murray, S. M., & Lord, S. R. (2004). Physiological risk factors for falls in older people with lower limb arthritis. *J Rheumatol, 31*(11), 2272-2279.

Tromp, A. M., Pluijm, S. M., Smit, J. H., Deeg, D. J., Bouter, L. M., & Lips, P. (2001). Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. *J Clin Epidemiol, 54*(8), 837-844.

Verbaken, J. (1986). Melbourne Edge Test.

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., & Lipton, R. (2002). Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. *J Am Geriatr Soc, 50*(9), 1572-1576.

West, R., Murphy, K. J., Armilio, M. L., Craik, F. I., & Stuss, D. T. (2002). Lapses of intention and performance variability reveal age-related increases in fluctuations of executive control. *Brain Cogn, 49*(3), 402-419.

Tables

Table 1. Descriptive Statistics According to Falls Category

	Variable	Non-fallers (n=66)		Fallers (n=42)	
		M(SD)		*M(SD)*	
Demographic, Health and Vision	Age	70.79	(7.63)	77.74**	(8.90)
	Gender	51women	15men	27women	15men
	NART	119.71	(5.30)	116.42*	(7.59)
	General health	1.55	(1.31)	2.74**	(1.11)
	Self-rated health	8.14	(1.61)	7.87	(1.47)
	Medications	1.58	(1.76)	4.48**	(3.87)
	Visual acuity	9.62	(1.23)	9.48	(1.13)
	Visual contrast	20.77	(1.86)	19.36**	(2.71)
Motor Function	Leg resistance (kg)	19.07	(7.19)	15.37	(13.09)
	Grip strength (kg)	26.57	(8.99)	19.42**	(8.40)
	Gait speed (seconds)	4.26	(1.59)	5.85**	(1.72)
	Balance	1.17	(.93)	3.72**	(3.80)
IIV	SRT CV	.25	(.09)	.29*	(.11)
	2-CRT CV	.19	(.05)	.24**	(.09)
	Flanker CV	.21	(.09)	.29**	(.14)
	Stroop word CV	.24	(.09)	.32**	(.10)

	Visual search CV	.20	(.06)	.25*	(.01)
Cognitive Function	TMT-A	35.70	(17.14)	50.81**	(28.09)
	TMT-B	68.67	(27.66)	104.58**	(56.79)
	TMT-costs	35.69	(22.00)	55.54**	(37.73)
	Verbal fluency	10.80	(2.76)	8.62**	(2.83)

Notes: Falls = multiple or one injurious in previous 2 years; NART = National Adult Reading Test; General health = number of diagnosed major medical conditions; Self-rated health = scale; Medications = number of regular prescribed medications; Balance = fixed point variance; CV = coefficient of variation: standard deviation/mean; SRT or 2-CRT = simple and two-choice reaction time; TMT-A or B= Trail making A or B; TMT-costs = TMT-B less TMT-A; VF = verbal fluency; t-test = between-group differences; IIV = Intraindividual variability.

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

Table 2. Logistic Regressions: Falls Regressed onto Demographic, Physical and Neurocognitive Variables in Individual Analyses

Group	Variable	Associations			
		B	*p*	Exp (B)	(95% CI)
Demographic, Health and Vision	Age	.100**	.000	1.105	1.049-1.163
	Gender	.636	.145	1.889	.804-4.438
	NART	-.051	.159	.922	.863-.985
	Medications	.315**	.001	1.370	1.144-1.642
	Self-rated health	-.061	.649	.941	.724-1.223
	General health	.556**	.005	1.744	1.187-2.562
	Visual acuity	.083	.654	1.108	1.050-1.169
	Visual contrast	-.164	.153	.849	.678-1.062
Motor Function	Leg resistance (kg)	-.025	.345	1.097	1.041-1.157
	Grip strength (kg)	-.082**	.008	.921	.867-.978
	Gait speed (seconds)	.440**	.006	1.552	1.132-2.128
	Balance	.610**	.002	1.840	1.248-2.712
IIV	NART	-.055	.141	.947	.880-1.018
	SRT CV	.263	.269	1.300	.816-2.072
	NART	-.048	.203	.953	.886-1.026
	2-CRT CV	.603*	.033	1.827	1.051-3.176

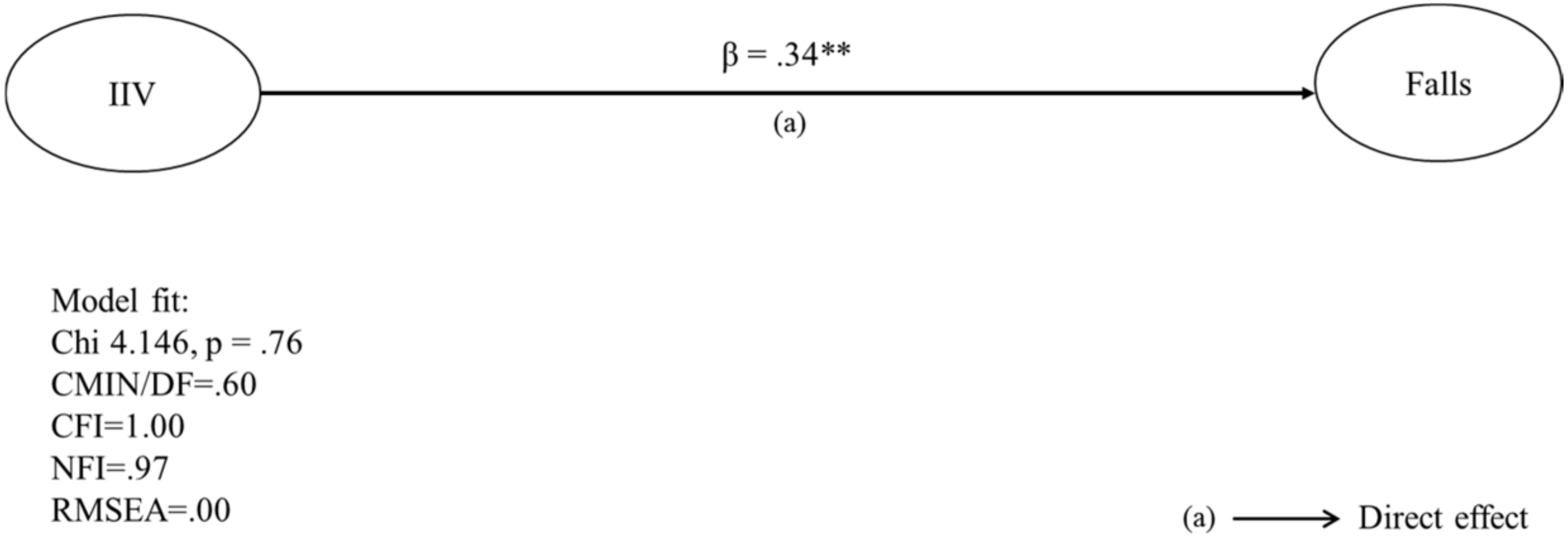
	NART	-.017	.686	.983	.905-1.068
	Flanker CV	.818*	.023	2.265	1.119-4.586
	NART	-.029	.447	.971	.900-1.047
	Stroop Word CV	.727*	.025	2.069	1.095-3.912
	NART	-.038	.316	.963	.894-1.037
	Visual search CV	.398	.189	1.488	.822-2.694
Executive Function	NART	-.031	.441	.970	.897-1.048
	TMT-costs	.302	.277	1.353	.785-2.332
	NART	-.008	.838	.992	.918-1.072
	Verbal fluency	-.931**	.005	.394	.207-.751

Notes: Falls = multiple or one injurious in last 24 months; NART = National Adult Reading Test; Medications = number of regular prescribed medications; Self-rated health = self-rating health scale; General health = number of diagnosed major medical conditions; Balance = fixed point center of pressure (COP) variance; (CV) = coefficient of variation: standard deviation/mean; SRT or 2-CRT = simple and two-choice Reaction Time. TMT-costs = Trail making B less A; IIV = Intraindividual variability; Age was a covariate throughout all analyses and NART was an additional covariate in all cognitive analyses; cognitive data were converted to *z*-scores.

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

Figures

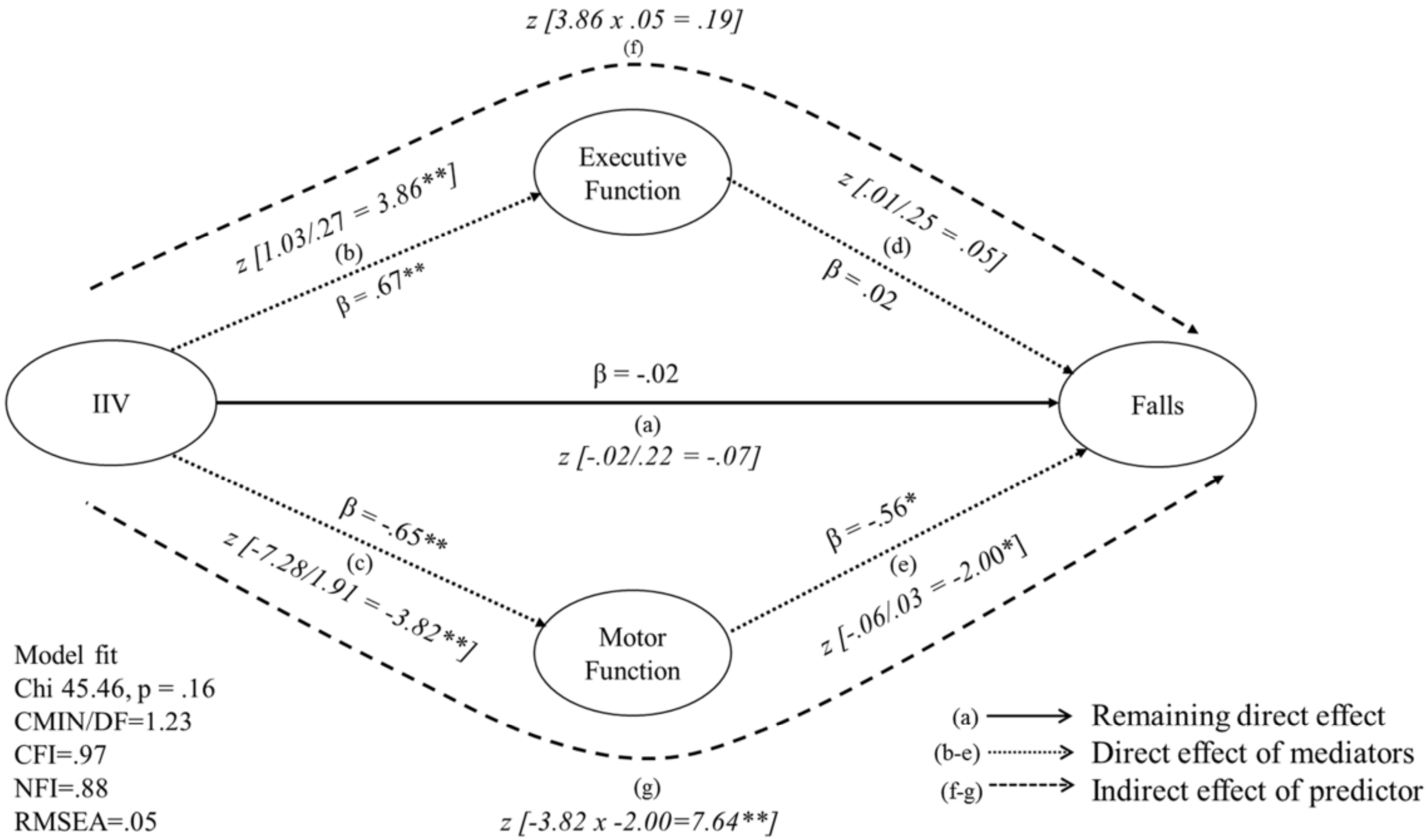
Figure 1. Direct path model



Model fit:
Chi 4.146, p = .76
CMIN/DF=.60
CFI=1.00
NFI=.97
RMSEA=.00

Note: Age and NART were covariates

Figure 2. Multiple Mediator Model



Note: Age and NART were covariates and just Age from Motor Function to Falls

Supplementary Table. Bivariate Correlations Between the Demographic, Motor and Cognitive Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.FALLS	-																				
2.Age	.387**	-																			
3.Gender	-.141	-.112	-																		
4.NART	-.249*	-.275**	.059	-																	
5.G. Health	.428**	.512**	-.057	-.184	-																
6.S. Health	-.084	-.109	.000	-.084	-.402**	-															
7.Meds	.458**	.331**	-.233*	-.269**	.555**	-.273**	-														
8.Vis. A	-.060	-.262**	.034	-.030	-.073	-.071	-.043	-													
9.Vis. C	-.298**	-.465**	.104	.334**	-.328**	.090	-.349**	.313**	-												
10.Leg-kg	-.181	-.234*	-.341**	.083	-.230*	.112	.120	-.033	.108	-											
11.Grip-kg	-.372**	-.356	-.582**	.135	-.365**	.151	-.195*	-.028	.296**	.594**	-										
12.Gait-sec.	.431**	.495**	-.031	-.497**	.385**	-.253**	.375**	-.049	-.402**	-.279**	-.427**	-									
13.Balance	.434**	.204	-.199	-.253*	.343**	-.357**	.620**	-.103	-.300**	.011	-.197	.393**	-								
14.SRT CV	.209*	.289**	.217*	.019	.175	-.003	-.045	-.124	-.056	-.147	-.290**	.164	-.134	-							
15.2-CRT CV	.315**	.305**	.060	-.163	.251**	-.083	.196*	-.042	-.139	-.046	-.238*	.352**	.237*	.253**	-						
16.Flanker CV	.331**	.409**	.040	-.392**	.387**	-.209*	.165	-.081	-.344**	-.236*	-.291**	.492**	.191	.299**	.456**	-					
17.Stroop CV	.371**	.446**	-.035	-.379**	.421**	-.125	.205*	.048	-.306**	-.225*	-.245*	.446**	.193	.242*	.453**	.648**	-				
18.Vis. S CV	.340**	.389**	-.210*	-.356**	.366**	-.218*	.311**	-.074	-.269**	-.152	-.202*	.495**	.309**	.230*	.330**	.468**	.433**	-			
19.TMT-A	.320**	.471**	-.151	-.352**	.497**	-.337**	.328**	-.150	-.596**	-.215*	-.314**	.556**	.335**	.146	.383**	.607**	.491**	.597**	-		
20.TMT-B	.394**	.495**	-.120	-.401**	.479**	-.198*	.265**	-.014	-.417**	-.279**	-.340**	.596**	.324**	.244*	.410**	.578**	.488**	.615**	.805**	-	
21.TMT-cost	.319**	.428**	-.160	-.321**	.380**	-.108	.230*	.044	-.297**	-.247*	-.259**	.460**	.282*	.231*	.268**	.448**	.400**	.522**	.495**	.914**	-
22.VF	.423**	-.428**	.034	.379**	-.291**	.103	-.167	-.136	.278**	.149	.348**	-.501**	-.253*	-.116	-.280**	-.438**	-.505**	-.146	-.418**	-.486**	-.386**

Notes: FALLS = multiple or one injurious in previous 2 years; NART = National Adult Reading Test; G. Health. = number of diagnosed major medical conditions; S. Health. = self-rating health scale; Meds = number of regular prescribed medications; Balance = fixed point center of pressure (COP) variance; Vis. A. or C. or S. = visual acuity or contrast or search; Gait-sec. = gait speed in cm/seconds; SRT or 2-CRT = simple and two-choice reaction time; CV = coefficient of variation; TMT-A or B= Trail making A or B; TMT-cost = TMT-B less TMT-A; VF = verbal fluency.

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