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RESEARCH ARTICLE

Intraindividual Variability of Neuromotor Function Predicts Falls Risk in Older Adults and those with Type 2 Diabetes

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ABSTRACT. This study was designed to examine the effect of increasing age and type 2 diabetes on the average responses and inter- and intraindividual variability of falls risk, reaction time, strength, and walking speed for healthy older adults and older persons with type 2 diabetes (T2DM). Seventy-five older individuals (controls) and 75 persons with T2DM aged between 50 and 79 years participated in the study. Assessments of falls risk, reaction time (RT), knee extension strength, and walking speed were conducted. The results revealed that advancing age for both control and T2DM groups was reflected by a progressive increase in falls risk, decreased leg strength and a decline (i.e., slowing) of reactions and gait speed. Conversely, the level of intraindividual variability for the RT, strength and gait measures increased with increasing age for both groups, with T2DM persons tending to be more variable compared to the healthy controls of similar age. In contrast to the intraindividual changes, measures of interindividual variability revealed few differences between the healthy elderly and T2DM individuals. Taken together, the findings support the proposition that intraindividual variability of neuromotor measures may be useful as a biomarker for the early detection of decline in physiological function due to age or disease.

Keywords: falls, reaction time, strength, variability, walking

Introduction

The natural time course of aging is typified by the onset and progression of adaptations in psychological and physiological processes that result in an overall decline in functional behavior. This general decline with aging is manifested across multiple processes leading to a pervasive slowing of the neuromotor subsystems, as reflected, for example, by the slowing of reaction time, decreases in preferred walking speed, and decline in finger tapping speed (Aoki & Fukuoka, 2010; Morrison & Newell, 2012; Morrison & Newell, 2017; Sommervoll, Ettema, & Vereijken, 2011; Spirduso, Francis, & MacRae, 2005). The functional decline of aging tends to be exacerbated with the onset and development of certain age-related diseases such as Parkinson's disease, essential tremor, dementia, and type 2 diabetes (T2DM). These diseases are all associated with age-related declines in physiological functions and can be manifested by concurrent slowing of the neural system and/or declines in the complexity of the motor output (Batterham, Bunce, Mackinnon, & Christensen, 2014; Bielak, Cherbuin, Bunce, & Anstey, 2014; Dykiert, Der, Starr, & Deary, 2012a; Lipsitz, 2002; Lipsitz & Goldberger, 1992; MacDonald, Nyberg, & Bäckman, 2006b; Newell, Vaillancourt, & Sosnoff, 2006; Vaillancourt & Newell, 2002).

However, the effects of aging and/or disease do not emerge at a single time point in chronological age but are progressive in nature through the lifespan of the individual as a function of a range of genetic and lifestyle influences (Granacher, Muehlbauer, Gollhofer, Kressig, & Zahner, 2011). For example, previous reports have shown decline in both simple and choice reaction time beginning in early adulthood (Bielak, Cherbuin, Bunce, & Anstey, 2014; Dykiert, Der, Starr, & Deary, 2012a). Similarly incremental decline of gait speed and diminished muscle strength has also been widely reported with increasing age (Granacher et al., 2011; Grimby, 1995; Himann, Cunningham, Rechnitzer, & Paterson, 1988; Moreland, Richardson, Goldsmith, & Clase, 2004; Oberg, Karsznia, & Oberg, 1993). Nevertheless, the majority of the research on the age-related decline in neuro-motor function has focused on the young-old (60–69 years), middle-old (70–79 years), and old-old (above 80 years) age groups with fewer investigations of the changes in the antecedent mid-life adult years.

There is growing evidence that, in addition to the decline in various physiological functions, older individuals become more variable in their movement output (Bielak, Cherbuin, Bunce, & Anstey, 2014; Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010; Bunce et al., 2017; Bunce, MacDonald, & Hultsch, 2004). Indeed, there is an increasing recognition that the pattern of variability over successive trials *within* a single person (i.e., intraindividual variability) reveals important organizational features of the neuromotor system and its output that can be distinct from the mean of a given variable and the degree of variability between persons (i.e., interindividual variability) (Newell & Corcos, 1993; Newell & Slifkin, 1998). It has been proposed that changes in intraindividual variability may be a more sensitive (bio)marker of age- and disease-related decline compared to distribution mean scores of physiological system outputs (Lovden, Li, Shing, & Lindenberger, 2007; Newell, Incledon, Bodfish, & Sprague, 1999; Sosnoff & Newell, 2006) and of the general health status of individuals (Lipsitz, 2002; MacDonald, Nyberg, & Bäckman, 2006b; MacDonald, Hultsch, & Dixon, 2003; MacDonald, Hultsch, & Dixon, 2011; Shipley, Der, Taylor, & Deary, 2008). There is a need to understand the relations of both inter- and intraindividual categories of variability in the aging and disease process. This is in part because the ergodic theorem (Molenaar, 2004; Molenaar, 2008) holds that

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the veracity of interindividual variability predicting intraindividual variability is dependent on the presence of certain conditions, including stationarity and the exchangeability of individuals in the population. However, the time-dependent patterns of the inter- and intraindividual categories of variability in aging and diseases such as T2DM are not well established.

While the impact of aging on intraindividual variability of specific motor functions has been the focus of several studies (Batterham, Bunce, Mackinnon, & Christensen, 2014; Bauermeister et al., 2017; Bunce et al., 2013; Graveson, Bauermeister, McKeown, & Bunce, 2016; Haynes, Bauermeister, & Bunce, 2017; Levin, Jacobs Jr, Ainsworth, Richardson, & Leon, 1999), there have been fewer direct examinations of intraindividual variability differences for individuals who develop age-related diseases such as type 2 diabetes. This is somewhat surprising given that individuals with T2DM tend to exhibit greater declines in balance control, reaction time, walking ability and strength compared to healthy persons of a similar age (Morrison, Colberg, Mariano, Parson, Vinik, 2010; Schwartz et al., 2002; Maurer, Burcham, & Cheng, 2005; Volpato, Leveille, Blaum, Fried, & Guralnik, 2005). One prediction is that the slowing of neuromotor function and increased intraindividual variability observed with the typical process of aging would be exacerbated for T2DM individuals of similar age since the emergence of this disease combined with decrements due to aging would lead to more profound changes in motor function. However, this perspective has not been comprehensively assessed for this population group with only a few direct examinations of movement variability and T2DM. Further, those that have been performed have tended to focus on performance of a single motor task such as reaction time (Whitehead, Dixon, Hultsch, & MacDonald, 2011) or walking (Lalli et al., 2013; Roman de Mettelinge et al., 2013). Given the widespread consequences of this disease on the neuromotor processes, it could be argued that greater insight as to any relation between intraindividual variability and motor function for T2DM persons would be gained from assessment across a range of neuromotor tasks for the same individual. Taken together, the statements provide support for further examination of the impact of T2DM on variability of motor function.

The central goal of this study was to investigate the relative contributions of inter- and intraindividual variability in the onset and progression of change (decline) in the neuromotor system as a function of age and disease (T2DM). Additionally, this study was designed to examine differences in inter/intraindividual variability for lower limb strength, motor function and falls risk between healthy individuals and those with T2DM aged 50–79 years. The generalizability of aging effects on inter- and intraindividual variability across motor tasks has received little study (though see Sosnoff & Newell, 2006). There are contrasting hypotheses that aging effects are both general across motor tasks and specific to a task or a category of motor tasks (Welford, 1984; Wiswell et al. 2001). The hypothesis that we test here in standard speed-related and strength motor tasks used to study aging is that there are generalizable across-task contributions to both inter- and intraindividual variability that strengthen with the progression of aging and the presence of T2DM. In addition, it was of interest to assess the relation between selected neuromotor measures (including mean and intraindividuals responses) and falls risk for the two groups across the three age ranges. To this effect, the relation between the falls risk scores and selected gait, reaction time, and strength measures, correlation analyses. It was predicted that stronger correlations would be observed between measures of intraindividual variability of motor function and falls risk, especially for the older persons with T2DM.

Methods

Participants

Seventy-five healthy individuals (controls) and 75 persons with T2DM between 50 and 79 years of age were recruited from the local community to participate in this study. Participants in the control and T2DM groups were evenly subdivided into three age decade ranges: 50–59 years; 60–69 years; and 70–79 years (n = 25 per age range). Participants provided informed written consent prior to inclusion in the study and all procedures complied with the University IRB guidelines.

Experimental Design

Participants completed the following evaluations related to their overall falls risk, simple reaction time (RT), lower limb strength and walking ability.

Falls Risk Assessment

An indication of falls risk was determined using the long-form physiological profile assessment (PPA). The PPA is a validated assessment tool that has been shown to predict risk of fall for a healthy older adults and those with diabetes (Lord, Menz, & Tiedemann, 2003; Vinik, Vinik, Colberg, & Morrison, 2015). The PPA consists of 15 different physiological assessments, including vision, sensation, proprioception, strength, reactions, general balance ability, and postural coordinated stability. Based upon the results of the individual assessments, a summative falls risk score (which ranges from –2 to +4) was generated with lower values denoting a lower falls risk and higher values indicating a heightened risk of suffering a fall (Lord, Menz, & Tiedemann, 2003).

Reaction Time

All participants completed a simple RT task using the upper limb (index finger). After completing 5 practice trials, each individual completed 20 experimental trials. Participants responded to a visual cue by depressing a timing

switch with their index finger. Prior to analysis, the RT data were trimmed by eliminating extremely fast trials using a lower boundary of 150 ms. Eliminated trials (26 trials total – <2%) were replaced with the individual's mean RT for that task.

Knee Extension Strength

All participants completed a series of isometric knee extension contractions with their preferred leg (this was defined as the leg they would use when kicking a ball). Individuals were seated on a raised chair with their knees at 90°. An adjustable leather strap was positioned approximately 10 cm above the lateral malleolus of the person's leg. The strap was attached to a strain gauge (American Weight Scale model tl330) that was affixed to a wall bracket. Each person was asked to produce their maximum isometric contraction at 90° of extension. Three trials were performed with 1–2 min rest between trials.

Gait

Walking performance was assessed using a 20 ft straight GAITRite pressure sensitive walking surface (CIR Systems Inc, Havertown PA). Individuals were instructed to look straight ahead and walk at their preferred walking pace. Three walking trials were performed (sample frequency 120 Hz). The GAITRite data were assessed using the Protokinetics PKMAS software (ProtoKinetics LLC). Average (mean) and inter- and intraindividual variability for the selected spatio-temporal gait variables (i.e., gait velocity, step length, and stride length) were calculated. These mean, inter- and intraindividual variability values were determined for each trial for each person.

Data Analysis

A repeated-measures generalized linear model was used to examine differences in average (mean) and intraindividual (SD) values as a function of age range (i.e., 50–59, 60–69, 70–79 years) and group (i.e., controls, T2DM). Planned contrasts were used to determine the loci for any significant age range effects. Levene's test of homogeneity of variance was used to assess whether there were differences in the pattern of interindividual variation (Hultsch, MacDonald, Dixon, 2002). The magnitude of any significant differences identified by the planned contrasts was expressed using partial eta-squared (η^2). Threshold values of .01, .06, and .14 were used for judging the η^2 values as small, moderate, and large (Cohen, 1988). Additionally, the relation between the falls risk scores and selected gait, reaction time, and strength measures were assessed by correlation analyses (using Pearson Product Moment Correlation Coefficients). All statistical analyses were performed using SAS statistical software (v 9.3, SAS Institute Inc., NC), with the risk of Type I error set at $p < .05$.

Results

Falls Risk Assessment

Figure 1 illustrates the pattern for the falls risk scores (average and interindividual variability results) across the three age ranges for the healthy control and the T2DM individuals. Overall, average falls risk scores increased significantly as a function of age range ($F_{2,145} = 5.09$, $p < .025$, $\eta^2 = 0.04$) and group ($F_{1,145} = 9.67$, $p < 0.001$, $\eta^2 = 0.15$). For the age effect, planned contrasts revealed that the falls risk scores for individuals aged 50–59 years were lower compared to the two older age groups. No difference in the falls risk scores was found between persons in the 60–69 and the 70–79 year age ranges. For the group effect, T2DM individuals within the 60–69 years and 70–79 years age ranges had a higher falls risk compared to the healthy controls of similar age. No significant age by group interaction effects were observed for the falls risk results.

Reaction Time

Average RT

Figure 2 illustrates the differences in the mean (Figure 2C), interindividual (Figure 2B), and intraindividual (Figure 2A) variability for the RT measures between the

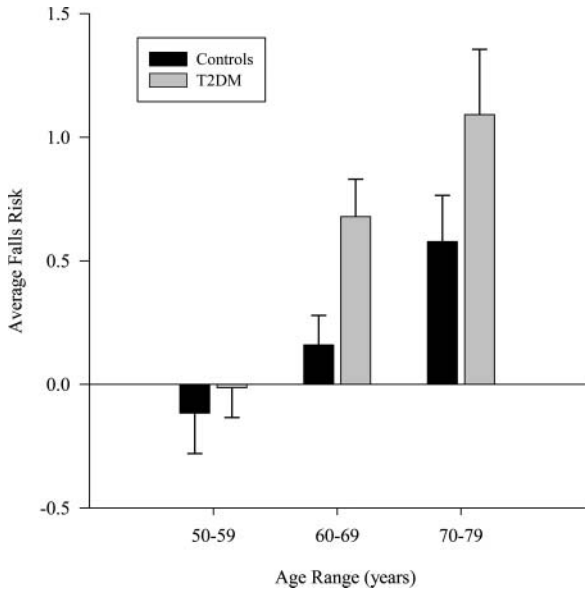

FIGURE 1. Bar graph depicting differences in the average (mean) falls risk values for the healthy elderly and the T2DM person across the 50–79 year age range. For the bar graphs, error bars represent one SE of the mean. The overall falls risk score was derived from the Physiological Profile Assessment (PPA) and ranged from -2 (low risk) to +4 (high risk).

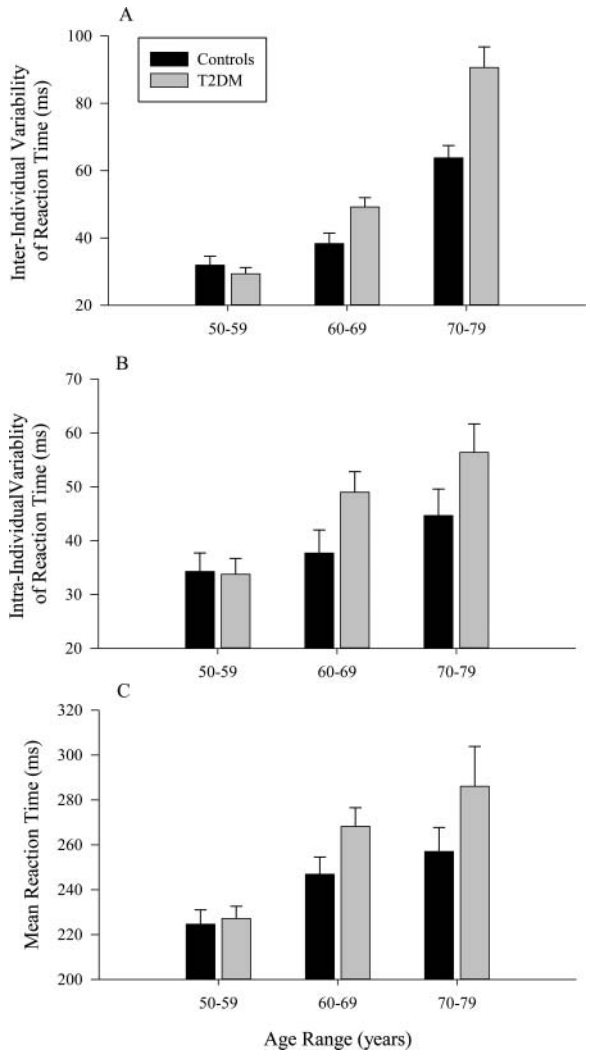

FIGURE 2. Bar graphs of mean (C), interindividual (A), and intraindividual (B) variability of simple reaction time between the two groups (i.e., healthy adults and T2DM) across the three age ranges. Error bars represent one SE of the mean.

healthy controls and the T2DM group across the three age ranges. Overall, the pattern of results revealed that the mean RT increased progressively with increasing age and was greater for T2DM. Inferential analysis confirmed these observations, with significant main effects for mean RT as a function of both age ($F_{2,145} = 8.86$, $p < .001$, $\eta^2 = 0.12$) and group ($F_{1,145} = 5.45$, $p < .05$, $\eta^2 = 0.08$). The average RT response was slower for older T2DM persons (i.e., 60–69 years and 70–79 years) in comparison to the healthy adults of similar age. For the age effect, mean RT was significantly lower (i.e., faster responses) for persons aged 50–59 years of age compared to persons within the 60–69 and 70–79-year-old ranges. No age by group interaction effect was found.

Intraindividual Variability of RT

Significant differences in the intraindividual (SD) variability of reaction time were found for age range ($F_{2,145} = 7.57$, $p < .006$, $\eta^2 = 0.05$) and between the two groups ($F_{1,145} = 5.10$, $p < .001$, $\eta^2 = 0.06$). For the age range effect, planned contrasts revealed that individuals within the youngest age range (50–59 years) had a significantly lower level of trial-to-trial variability than the older two age groups. There were no differences in the intraindividual (SD) variability measures between persons in the 60–69 and 70–79 year groups. For the group effect, older T2DM individuals (i.e., 60–69 years and 70–79 years) exhibited greater intraindividual variability across trials compared to the responses of the healthy individuals of similar age.

Interindividual Variability of RT

For the RT data, no significant differences in interindividual variance of hand reaction time were found as a function of age range ($F_{2,148} = 1.68$, $p = .189$) or group ($F_{1,148} = 0.95$, $p = .33$).

Knee Extension Strength

Average Strength

Figure 3 illustrates the differences in the mean (Figure 3C), interindividual (Figure 3B), and intraindividual (Figure 3A) variability for the knee extension strength values for both groups across the three age ranges. Significant differences in the mean values for knee extension strength were found for age range ($F_{2,145} = 15.64$, $p < .01$, $\eta^2 = 0.04$) and group ($F_{1,145} = 16.30$, $p < .01$, $\eta^2 = 0.07$). Across the three age ranges, knee extension strength decreased systematically, with planned contrasts revealing significant differences between all three age ranges. Further, the strength measure for the control persons was greater overall compared to the T2DM group across all age ranges. No age by group interaction effect was found.

Intraindividual Variability of Strength

Significant main effects were observed for the IIV of knee extension strength across the three age ranges ($F_{2,145} = 3.91$, $p < .05$, $\eta^2 = 0.05$). Overall, IIV strength measures increased with increasing age, with planned contrasts revealing significantly increased variability for persons within the 70–79-year-old persons compared to those aged 50–60 years and 60–70 years. No main effect for group or age-by-group interaction effects were found.

Interindividual Variability of Strength

For knee extension strength, the results of Levene's test revealed no significant differences in (interindividual)

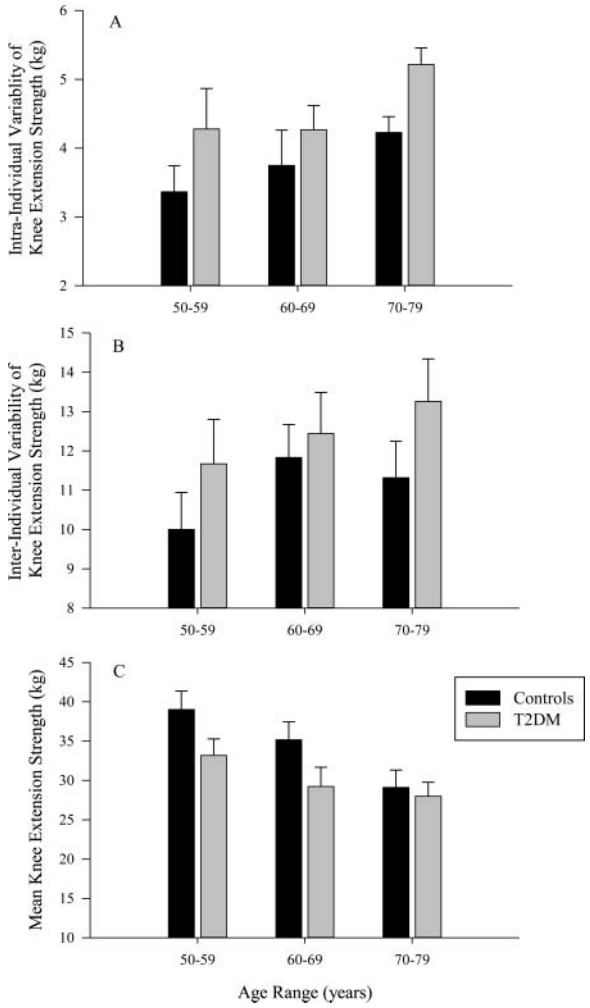

FIGURE 3. Bar graphs of mean (C), interindividual (B), and intraindividual (A) variability differences in knee extension strength. Results are shown for each of the two groups across the three age ranges. Error bars represent one SE of the mean.

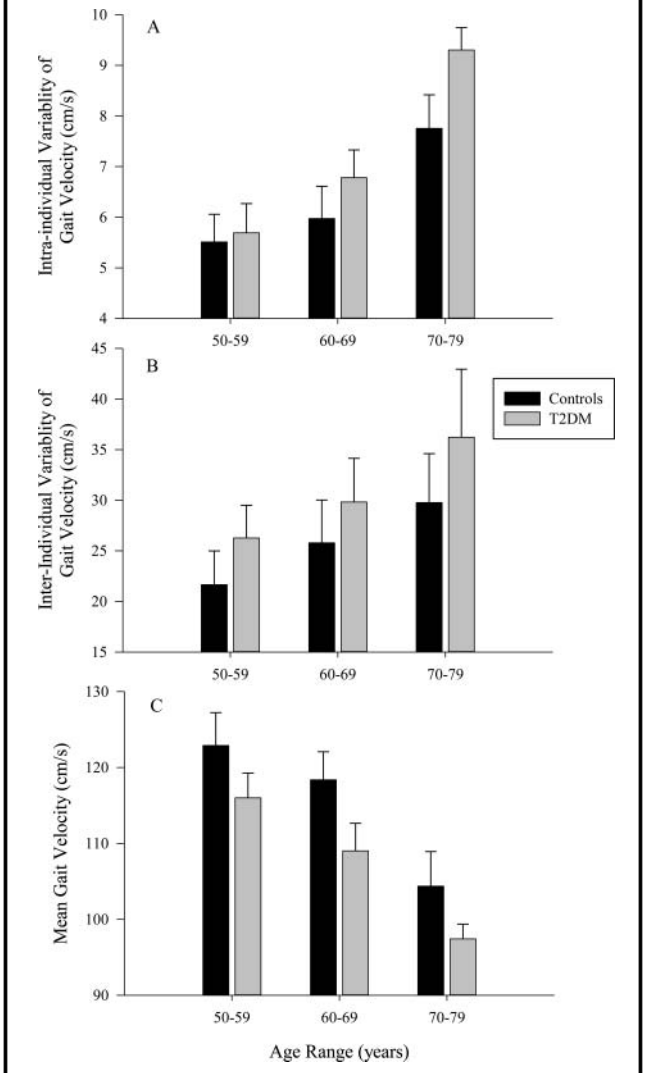

FIGURE 4. Bar graphs of mean (C), interindividual (B), and intraindividual (A) variability differences in gait speed between the two groups across the three age ranges. For the bar graphs, error bars represent one SE of the mean.

variance as a function of age range ($F_{2,148} = 0.13$, $p = .189$) or group ($F_{1,148} = 0.07$, $p = .33$).

Gait

Average Measures for Gait

Figure 4 illustrates the general change in average gait velocity (Figure 4C) as a function of age and group. The pattern of interindividual (Figure 4B) and intraindividual (Figure 4A) variability results for gait velocity across the three age ranges for the healthy control persons and the T2DM individuals are also shown. For gait velocity, a significant main effect was observed for both age range ($F_{2,145} = 13.01$, $p < .001$, $\eta^2 = 0.14$) and group ($F_{1,145} = 6.66$, $p < .01$, $\eta^2 = 0.04$). Average gait velocity was significantly lower for the T2DM group in comparison to the healthy adults across all age ranges. For the age effect, gait velocity decreased progressively as a function of increasing age with significant differences being observed between the 70–79-year-old persons and individuals within the other two age ranges.

Significant main effects were also found for step and stride length as a function of age (step length $F_{2,145} = 4.29$ $\eta^2 = 0.02$; stride length $F_{2,145} = 4.92$, $\eta^2 = 0.03$, all p's $< .05$) and group (step length $F_{1,145} = 12.91$, $\eta^2 = 0.03$; stride length $F_{1,145} = 15.56$ $\eta^2 = 0.05$, all p's $< .01$). For the age effect, persons within the 70–79 years range within both age groups had shorter stride and step lengths compared to individuals within the 50–59 and 60–69 years age ranges. Further, persons with T2DM had shorter stride lengths and step lengths in regards to their step/stride lengths in comparison

to the healthy controls (all p's $< .05$). No interaction effects were observed for any of these measures.

Intraindividual Variability of Gait

Significant differences in the IIV of gait velocity were found for age ($F_{2,145} = 9.22$, $p < .05$, $\eta^2 = 0.05$) and group ($F_{1,145} = 5.47$, $p < .05$, $\eta^2 = 0.03$). Overall, the pattern of variability for gait velocity increased with increasing age, with planned contrasts revealing significantly increased variability for persons within the 70–79 years old persons compared to those aged 50–60 years. Additionally, the gait velocity of the healthy adults across all age ranges was less variable compared to persons with T2DM.

In addition to the gait velocity measures, significant main effects were also found for step and stride length measures as a function of age (step length $F_{2,145} = 4.37$, $\eta^2 = 0.04$; stride length $F_{2,145} = 4.94$, $\eta^2 = 0.05$; p's $< .05$) and group (step length $F_{1,145} = 12.91$, $\eta^2 = 0.08$; stride length $F_{1,145} = 15.56$, $\eta^2 = 0.10$; p's $< .01$). Consistent with the velocity results, older persons (70-79 years) within both groups were more variable in terms of step and stride length compared to individuals within the 50–59 years age range. Further, persons with T2DM were more variable in regards to their step/stride lengths in comparison to the healthy controls (all p's $< .05$). No interaction effects were observed for any of the intraindividual measures.

Interindividual Variability of Gait

For gait velocity, no significant differences were found as a function of age range ($F_{2,148} = 1.66$, $p = .193$) or group ($F_{1,148} = 0.30$, $p = .586$). However, the Levene's test revealed significant differences in (interindividual) variability for both stride length ($F_{1,148} = 4.15$, $p < .05$) and step length as a function of group ($F_{1,148} = 4.99$, $p < .05$). No effect for age range was observed for these two measures.

Correlation Analysis

To assess the relation between the falls risk scores and selected gait, reaction time, and strength measures for each of the two groups within each age range, correlation analyses were performed using Pearson's correlation coefficient. Consistent with the previous analyses, correlations were performed separately for the mean and intraindividual results.

Correlation based upon Average Values

The results of the cross correlation analysis performed on both the mean and IIV values are illustrated in Table 1. Briefly, for both the control and the T2DM groups, significant correlations were found between falls risk values and reaction time for individuals within 60–69 years and 70–79 years age ranges. Similarly, knee extension strength was significantly correlated with falls risk for both groups but only within the older age ranges. However, it should be noted these specific assessments are used (in part) to derive the overall falls risk score. For the other measures, no significant correlations were found between the selected gait measures (i.e., velocity, step length and stride length) and falls risk scores as a function of age range or group. Similarly, no significant correlations were observed between any of the gait measures and the mean values for reaction time or strength.

Correlations based upon Intraindividual Variability Values

For healthy adults within the 50–59 year age range, no significant correlations were found between any of the selected metrics. Within the 60–69 year age range, there were significant correlations between falls risk scores and intraindividual variability measures for step length, stride length and RT. For older adults (70–79 years) significant correlations were found between falls risk scores and

TABLE 1. Summarized results of the cross correlation analysis.

	Healthy elderly			T2DM		
Variables	50–59 years	60–69 years	70–79 years	50–59 years	60–69 years	70–79 years
Correlations based upon mean values						
Falls Risk – Reaction Time	0.16	0.51*	0.43*	0.14	0.44*	0.37*
Falls Risk – Knee Extension	−0.27	−0.31	−0.44*	−0.16	−0.39*	−0.42*
Correlations based upon IIV values						
Falls Risk – IIV of step length	0.14	0.46*	0.51*	0.26	0.40*	0.42*
Falls Risk – IIV of stride length	0.18	0.41*	0.41*	0.22	0.38*	0.16
Falls Risk – IIV of gait velocity	0.28	0.30	0.55*	0.08	0.54*	0.45*
Falls Risk – IIV of RT	0.07	0.42*	0.45*	0.09	0.84*	0.50*
IIV of knee extension – IIV of gait velocity	0.04	0.29	0.40*	0.26	0.42*	0.39*
IIV of gait velocity – IIV of RT	0.17	0.22	0.15	0.39*	0.41*	0.48*

intraindividual variability measures for gait velocity, step length, stride length and hand reaction time. For this same age range, correlations between variability of knee extension strength and gait velocity were also seen.

For the T2DM adults, significant correlations were observed between intraindividual variability measures for falls risk and IIV of step length, hand reaction time and gait velocity. Further, for T2DM persons between 60 and 79 years, variability of knee extension strength was strongly correlated with IIV measures of gait velocity while, for T2DM adults within the 70–79 year range, variability of gait velocity was correlated with the intraindividual variability measures for reaction time.

Discussion

The aim of the current study was to examine the patterns of inter- and intraindividual variability of falls risk, leg strength, reaction time and walking ability for both healthy older adults and older persons with T2DM. As expected, the results revealed that increasing age for both groups was reflected by a systematic increase in falls risk and a decline (i.e., slowing) of general motor function in reaction time and walking speed (Dykiert, Der, Starr, & Deary, 2012b; Himann, Cunningham, Rechnitzer, & Paterson, 1988; Morrison et al., 2016; Welford, 1988). Importantly, in addition to this neuromotor slowing, there was increased intraindividual variability for these same measures as a function of increasing age, with the older T2DM individuals being more variable compared to healthy controls.

Slowing of the Neuromotor System with Age and Disease

Aging is typically characterized by a functional decline across multiple physiological and behavioral systems, with one pervasive consequence being a general slowing of neuromotor output (Haynes, Bauermeister, & Bunce, 2017; Morrison & Newell, 2017; Spirduso, Francis, & MacRae, 2005; Welford, 1988). This slowing can be manifested across a range of movement and behavioral outputs at all levels of the biological system, being reflected by an increment in reaction time, slowing of finger tapping speed and decreases in preferred walking speed for example (Aoki & Fukuoka, 2010; Himann, Cunningham, Rechnitzer, & Paterson, 1988). While it is generally accepted that these declines occur with increasing age and/or the onset of age-related diseases, our findings show (see Figures 2 and 3) that this trend of response slowing does not simply emerge at a single time point in chronological age spectrum but that the declines are progressive in nature and individual specific over the lifespan. This finding is important to emphasize given that the majority of research as to the age-related declines in function has tended to focus on changes from young-old (60–69 years) through to the old–old (above 80 years) age ranges with less attention paid to what happens through the mid-life adult years.

The current study was designed to assess both the decline in function with age and disease and the change in variability across a wider age range encompassing mid-life (i.e., 50–59 years) and the more typically described older age brackets (i.e., 60–69 and 70–79 years). The findings are consistent with previous reports (Bielak, Cherbuin, Bunce, & Anstey, 2014; Dykiert, Der, Starr, & Deary, 2012a) in showing for the motor tasks studied here that the mid-life (50–59 years) age bracket was on average significantly stronger and faster in responding than those persons within the 60–69 years and even more so the 70–79 year age range. This was the case for both the healthy and T2DM groups although the healthy group was generally stronger (within the lower limb) and faster across both RT and gait speed. We did not have a younger adult contrast group but previous studies have also shown a general slowing of responding in RT and MT between 20 and 50 years of age (Bielak, Cherbuin, Bunce, & Anstey, 2014). Moreover, the age contrasts reported here on speed of responding are cross-sectional leaving the need for a full longitudinal account of intraindividual variability with aging.

Intraindividual Variability in Diabetes

There is a growing body of research supporting the proposition that increases in intraindividual variability may serve as a potential biomarker for mapping the decline in physiological function seen with increasing age and/or onset of age-related diseases such as diabetes. Indeed, there have been numerous reports focusing on the decline in various physiological functions and the relation to intraindividual variability for healthy adults as a consequence of aging (Batterham, Bunce, Mackinnon, & Christensen, 2014; Bunce et al., 2016; Graveson, Bauermeister, McKeown, & Bunce, 2015; Haynes, Bauermeister, & Bunce, 2017; Levin et al., 1999; MacDonald, Nyberg, & Bäckman, 2006b; MacDonald, Hultsch, & Bunce, 2006a). A similar pattern of change in intraindividual variability would be expected for older persons with T2DM, especially since these individuals often exhibit declines in neuromotor function greater than those typically seen for healthy adults of similar age (Volpato et al., 2005, Vinik et al., 2015; Colberg et al., 2016; Schwartz et al., 2008). However, there has been less attention given to assessing intraindividual variability of motor responses for T2DM individuals. In one of the few studies that assessed intraindividual variability, Whitehead, Dixon, Hultsch, and MacDonald (2011)) reported a general slowing of RT responses but did not find any consistent evidence for intraindividual variability differences between healthy older adults and persons with T2DM. Similarly, increases in gait variability have also been reported for older person with T2DM (Lalli et al., 2013; Roman de Mettelinge et al. 2013).

However, specific comparisons matching the pattern of change in intraindividual variability across different movement and cognitive tasks between older adults with T2DM

and healthy adults have not been systematically performed to date. Hence, it is unclear whether T2DM individuals show a similar general trend for increased intraindividual variability during motor tasks as reported for healthy adults of similar age. This assessment would seem to be more important given the link between slower reaction times, decreased strength, declines in gait speed and increased likelihood of suffering a fall for older persons with T2DM (Maurer, Burcham, & Cheng, 2005; Morrison et al., 2010; Schwartz et al., 2008; Vinik, Vinik, Colberg, & Morrison, 2015; Volpato et al., 2005). One prediction is that any increases in intraindividual variability would be more pronounced for older T2DM adults based upon the declines associated with both increasing age coupled with the emergence of disease. The results of the current study support this general premise. Not only were T2DM adults weaker and slower overall (in regards to the average reaction time and preferred walking speed), there was also a pronounced increase in the within-subject variability across these same measures that was greater in magnitude and generality than that seen for the healthy older adults.

One of the more prominent findings to emerge from the correlation analysis was that, with increasing age, there was an increase in the number of paired measures that were positively correlated. Further, correlational results based upon intraindividual variability measures revealed a greater overall number of significant relations compared to the findings using the mean values. For example, for healthy persons within the 50–59 year age range, no significant correlations between falls risk and any of the neuromotor measures were observed. For adults over 60 years of age, correlations based upon mean values revealed significant relations only between falls risk and reaction time and leg strength. However, as both RT and knee extension values are used in the derivation of overall falls risk scores, this result is less compelling. What was more notable was the lack of any significant correlations between any of the gait measures and falls risk or between average RT values, leg strength or gait measures.

In contrast, significant correlations were found between falls risk scores and intraindividual variability measures for gait velocity, step length, stride length, and hand reaction time for healthy adults within the 70–79 year age range. Similarly, for the T2DM persons across all three age ranges, significant correlations were seen between intraindividual variability measures for hand reaction time and gait velocity. For T2DM adults within the 70–79 year ranges, correlations between falls risk and intraindividual variability measures related to gait velocity, step length and hand reaction time were observed. Significant relations between variability measures of leg strength and selected gait metrics were also found in both the older controls and the T2DM groups. From a general perspective, these collective findings may point to greater interdependence between aspects of the respective neuromotor systems as a consequence of increasing age and/or the emergence of diabetes. This loss of independence between various neuromotor outputs is consistent with the general rationale underlying the basis for the changes in physiological complexity and the loss of flexibility in motor control with aging and disease (Lipsitz & Goldberger, 1992; Vaillancourt & Newell, 2002). In addition, the emergence of a greater number of significant correlations based upon within-subject variability measures in comparison to correlational analyses performed using mean values is also a relevant finding. One explanation is that these variability measures may provide additional insight as to subtle changes in neuromotor function, highlighting the development of stronger coupling between selected physiological processes that occurs within increasing age and disease.

Inter- and Intraindividual Variability

While the age related patterns of inter- and intravariability showed relatively parallel trends for RT, lower limb strength and gait velocity in both population groups (e.g., see Figures 2–4), only the intravariability results reached levels of significance. For the RT and gait velocity measures, there was a progressive slowing of the system over advancing age while the strength measures showed an overall decline. These declines were reflected by significant increases in intravariability for these same measures that were more pronounced for older individuals with T2DM. However, the results of the interindividual changes revealed few notable changes even though the overall interindividual data tended to run parallel to the changes in intravariability results of age and population groups. Taken together, these results indicate that selected measures of intravariability were more sensitive to changes due to increasing age and the development of disease compared to standard measures of between-subject variance (Lovden, Li, Shing, & Lindenberger, 2007; Newell, Incledon, Bodfish, & Sprague, 1999; Sosnoff & Newell, 2006). Further, these findings support the general premise that intraindividual variability changes could serve as a biomarker for capturing progressive declines in physiological function as a consequence of the typical process of aging (Lovden, Li, Shing, & Lindenberger, 2007; Newell, Incledon, Bodfish, & Sprague, 1999; Sosnoff & Newell, 2006) and the general health status of individuals (Lipsitz, 2002; MacDonald, Hultsch, & Dixon, 2003; MacDonald, Nyberg, & Bäckman, 2006b; MacDonald, Hultsch, & Dixon, 2011; Shipley, Der, Taylor, & Deary, 2008).

One additional point that should be noted is that our analyses of inter- and intravariability were all based on the amount of respective variation and distributional standard deviation measures. It has been postulated that time and frequency dependent analyses of variability may be more sensitive than distributional measures to age- and disease-related changes (Sosnoff & Newell, 2006). A more complete test of this proposition will

require a longitudinal design and experimental tasks that afford the more dynamic measures of variability.

Conclusions

Overall, both increasing age and the emergence of type 2 diabetes were associated with increased falls risk, the basis being the general decline in walking ability, reaction time, and lower limb strength. These declines were also reflected by significant increases in intra- (but not inter-) individual variability of the neuromotor responses. These findings supported our original prediction, in that increases in aging and the presence of T2DM would be characterized by enhanced intraindividual motor variability. Consequently, the increased falls risk for older individuals would appear to not only be linked with loss of strength and the general slowing of motor functions (i.e., gait, reaction time), but also with increased variability of these same motor outputs. These findings indicate that intravariability measures may be useful as a biomarker for charting age- and disease-related declines in physiological function.

REFERENCES

Aoki, T., & Fukuoka, Y. (2010). Finger tapping ability in healthy elderly and young adults. *Medicine and Science In Sports And Exercise*, *42*, 449–455.

Ann V. Schwartz, Eric Vittinghoff, Deborah E. Sellmeyer, Kenneth R. Feingold, Nathalie de Rekeneire, Elsa S. Strotmeyer, Ronald. I. Shorr, Aaron I. Vinik, Michelle C. Odden, Seok Won Park, Kimberly A. Faulkner, Tamara B. Harris. (2008). Diabetes-related complications, glycemic control, and falls in older adults. *Diabetes Care*, *31*(3), 391–396.

Batterham, P. J., Bunce, D., Mackinnon, A. J., & Christensen, H. (2014). Intra-individual reaction time variability and all-cause mortality over 17 years: A community-based cohort study. *Age Ageing*, *43*, 84–90.

Bauermeister, S., Sutton, G., Mon-Williams, M., Wilkie, R., Graveson, J., Cracknell, A., . . . Bunce, D. (2017). Intraindividual variability and falls in older adults. *Neuropsychology*, *31*, 20–27.

Bielak, A. A., Cherbuin, N., Bunce, D., & Anstey, K. J. (2014). Intraindividual variability is a fundamental phenomenon of aging: Evidence from an 8-year longitudinal study across young, middle, and older adulthood. *Developmental Psychology*, *50*, 143–151.

Bielak, A. A., Hultsch, D. F., Strauss, E., MacDonald, S. W., & Hunter, M. A. (2010). Intraindividual variability is related to cognitive change in older adults: Evidence for within-person coupling. *Psychol Aging*, *25*, 575–586.

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? *Journal Of The International Neuropsychological Society*, *19*, 971–976.

Bunce, D., Haynes, B. I., Lord, S. R., Gschwind, Y. J., Kochan, N. A., Reppermund, S., . . . Delbaere, K. (2017). Intraindividual stepping reaction time variability predicts falls in older adults with mild cognitive impairment. *Journals of Gerontology. Series a, Biological Sciences and Medical Sciences*, *72*, 832–837. doi:10.1093/gerona/glw164.

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 and Cognition*, *56*, 320–327.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Earlbaum Associates

Colberg, S. R., Sigal, R. J., Yardley, J. E., Riddell, M. C., Dunstan, D. W., Dempsey, P. C., . . . Tate, D. F. (2016). Physical activity/exercise and diabetes: A position statement of the American diabetes association. *Diabetes Care*, *39*, 2065–2079 doi:10.2337/dc16-1728. PMID:27926890

Dykiert, D., Der, G., Starr, J. M., & Deary, I. J. (2012a). Age differences in intra-individual variability in simple and choice reaction time: Systematic review and meta-analysis. *PLoS One*, *7*, e45759.

Dykiert, D., Der, G., Starr, J. M., & Deary, I. J. (2012b). Sex differences in reaction time mean and intraindividual variability across the life span. *Developmental Psychology*, *48*, 1262–1276.

Granacher, U., Muehlbauer, T., Gollhofer, A., Kressig, R. W., & Zahner, L. (2011). An intergenerational approach in the promotion of balance and strength for fall prevention – a mini-review. *Gerontology*, *57*, 304–315.

Graveson, J., Bauermeister, S., McKeown, D., & Bunce, D. (2016). Intraindividual reaction time variability, falls, and gait in old age: a systematic review. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *71*, 857–864.

Grimby, G. (1995). Muscle performance and structure in the elderly as studied cross-sectionally and longitudinally. *Journals of Gerontology. Series A, Biological Sciences and medical Sciences*, *50* Spec No, 17–22

Haynes, B. I., Bauermeister, S., & Bunce, D. (2017). Age and intra-individual variability. In N. A. Pachana (Ed.), *Encyclopedia of geropsychology* (pp 49–57). Singapore: Springer Singapore.

Himann, J. E., Cunningham, D. A., Rechnitzer, P. A., & Paterson, D. H. (1988). Age-related changes in speed of walking. *Medicine and Science in Sports and Exercise*, *20*, 161–166.

Hultsch D. F., MacDonald S. W., Dixon R. A. (2002). Variability in reaction time performance of younger and older adults. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *57*, P101–115.

Lalli, P., Chan, A., Garven, A., Midha, N., Chan, C., Brady, S., . . . Toth, C. (2013). Increased gait variability in diabetes mellitus patients with neuropathic pain. *Journal of Diabetes and Its Complications*, *27*, 248–254.

Levin, S., Jacobs, D. R. Jr, Ainsworth, B. E., Richardson, M. T., & Leon, A. S. (1999). Intra-individual variation and estimates of usual physical activity. *Annals of Epidemiology*, *9*, 481–488.

Lipsitz, L. A. (2002). Dynamics of stability: The physiologic basis of functional health and frailty. *Journal of Gerontology A Biological Sciences & Medical Sciences*, *57*, B115–125.

Lipsitz, L. A., & Goldberger, A. L. (1992). Loss of 'complexity' and aging: Potential applications of fractals and chaos theory to senescence. *Journal of the American Medical Association*, *267*, 1806–1809.

Lord, S. R., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls risk assessment and prevention. *Physical Therapy*, *83*, 237–252.

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*, 2827–2838.

MacDonald, S. W., Hultsch, D. F., & Bunce, D. (2006a). Intraindividual variability in vigilance performance: Does degrading visual stimuli mimic age-related "neural noise"? *Journal of Clinical and Experimental Neuropsychology*, *28*, 655–675.

MacDonald, S. W., Hultsch, D. F., & Dixon, R. A. (2003). Performance variability is related to change in cognition: Evidence from the victoria longitudinal study. *Psychology and Aging*, *18*, 510–523.

MacDonald, S. W., Hultsch, D. F., & Dixon, R. A. (2011). Aging and the shape of cognitive change before death: Terminal decline or terminal drop? *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *66*, 292–301.

MacDonald, S. W. S., Nyberg, L., & Bäckman, L. (2006b). Intra-individual variability in behavior: Links to brain structure, neurotransmission and neuronal activity. *Trends in Neurosciences*, *29*, 474–480.

Maurer, M. S., Burcham, J., & Cheng, H. (2005). Diabetes mellitus is associated with an increased risk of falls in elderly residents of a long-term care facility. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *60*, 1157–1162.

Molenaar, P. C. (2004). A manifesto on psychology as idiographic science: Bringing the person back into scientific psychology, this time forever. *Measurement*, *2*, 201–218.

Molenaar, P. C. (2008). On the implications of the classical ergodic theorems: Analysis of developmental processes has to focus on intra-individual variation. *Developmental Psychobiology*, *50*, 60–69.

Moreland, J. D., Richardson, J. A., Goldsmith, C. H., & Clase, C. M. (2004). Muscle weakness and falls in older adults: A systematic review and meta-analysis. *Journal of the American Geriatrics Society*, *52*, 1121–1129.

Morrison S, Colberg SR, Mariano M, Parson HK, Vinik AI (2010). Balance training reduces falls risk in older individuals with type 2 diabetes. *Diabetes Care*, *42*, 277–287.

Morrison, S., Colberg, S. R., Parson, H. K., Neumann, S., Handel, R., Vinik, E. J., . . . Vinik, A. I. (2016). Walking-induced fatigue leads to increased falls risk in older adults. *Journal of the American Medical Directors Association*, *17*, 402–409.

Morrison, S., & Newell, K. M. (2012). Aging, neuromuscular decline, and the change in physiological and behavioral complexity of upper-limb movement dynamics. *Journal of Aging Research*, *2012*, 891218. doi:10.1155/2012/891218.

Morrison, S., & Newell, K. M. (2017). Aging and slowing of the neuromotor system. In N. A. Pachana (Ed.), *Encyclopedia of geropsychology* (pp. 215–226). Singapore: Springer Singapore.

Newell, K. M., & Corcos, D. M. (1993). Issues in variability and motor control. In K. M. Newell & D. M. Corcos (Eds.), *Variability and motor control* (pp. 1–12). Champaign: Human Kinetics.

Newell, K. M., Incledon, T., Bodfish, J. W., & Sprague, R. L. (1999). Variability of stereotypic body-rocking in adults with mental retardation. *American Journal of Mental Retardation*, *104*, 279–288.

Newell, K. M., & Slifkin, A. B. (1998). The nature of movement variability. In J. J. Piek (Ed.), *Motor behavior and human skill*. Champaign, IL: Human Kinetics.

Newell, K. M., Vaillancourt, D. E., & Sosnoff, J. J. (2006). Aging, complexity, and motor performance: Healthy and disease states. In J. E. Birren & W. Schaie (Eds.), *Handbook of the psychology of aging* 6th ed., pp 163–182). Burlington: Academic Press.

Oberg, T., Karsznia, A., & Oberg, K. (1993). Basic gait parameters: Reference data for normal subjects, 10–79 years of age. *Journal of Rehabilitation Research and Development*, *30*, 210–223.

Roman de Mettelinge, T., Delbaere, K., Calders, P., Gysel, T., Van Den Noortgate, N., & Cambier, D. (2013). The impact of peripheral neuropathy and cognitive decrements on gait in older adults with type 2 diabetes mellitus. *Archives of Physical Medicine and Rehabilitation*, *94*, 1074–1079.

Schwartz A. V., Hillier T. A., Sellmeyer D. E., Resnick H.E., Gregg E., Ensrud K.E., . . . Cummings SR. (2002). Older women with diabetes have a higher risk of falls: A prospective study. *Diabetes Care*, *25*, 1749–1754.

Schwartz A. V., Vittinghoff E., Sellmeyer D. E., Feingold K. E., de Rekeneire N., Strotmeyer E. S., . . . Harris T. B.. (2008). Diabetes-related complications, glycemic control, and falls in older adults. *Diabetes Care*, *31*(1), 391–396.

Shipley, B. A., Der, G., Taylor, M. D., & Deary, I. J. (2008). Cognition and mortality from the major causes of death: The health and lifestyle survey. *Journal of Psychosomatic Research*, *65*, 143–152.

Sommervoll, Y., Ettema, G., & Vereijken, B. (2011). Effects of age, task, and frequency on variability of finger tapping. *Perceptual and Motor Skills*, *113*, 647–661.

Sosnoff, J. J., & Newell, K. M. (2006). The generalization of perceptual-motor intra-individual variability in young and old adults. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *61*, P304–310.

Spirduso, W. W., Francis, K. L., & MacRae, H. H. (2005). *Physical dimensions of aging*. Champaign, IL: Human Kinetics

Vaillancourt, D. E., & Newell, K. M. (2002). Changing complexity in human behavior and physiology through aging and disease. *Neurobiology of Aging*, *23*, 1–11.

Vinik, A. I., Vinik, E. J., Colberg, S. R., & Morrison, S. (2015). Falls risk in older adults with type 2 diabetes. Editor: Strotmeyer, E. S. *Clinics in Geriatric Medicine*, *31*(1), 89–99.

Volpato, S., Leveille, S. G., Blaum, C., Fried, L. P., & Guralnik, J. M. (2005). Risk factors for falls in older disabled women with diabetes: The women's health and aging study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *60*, 1539–1545.

Welford, A. (1984). Between bodily changes and performance: Some possible reasons for slowing with age. *Experimental Aging Research*, *10*, 73–88.

Welford, A. T. (1988). Reaction time, speed of performance, and age. *Annals of the New York Academy of Sciences*, *515*, 1–17.

Whitehead, B. P., Dixon, R. A., Hultsch, D. F., & MacDonald, S. W. S. (2011). Are neurocognitive speed and inconsistency similarly affected in type 2 diabetes? *Journal of Clinical and Experimental Neuropsychology*, *33*, 647–657.

Wiswell, R. A., Hawkins, S. A., Jaque, S. V., Hyslop, D., Constantino, N., Tarpenning, K., . . . Schroeder, E. T. (2001) Relationship between physiological loss, performance decrement, and age in master athletes. *Journals of Gerontology. Series a, Biological Sciences and Medical Sciences*, *56*, M618–626.

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