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Running Head: INTRAINDIVIDUAL VARIABILITY ACROSS ADULTHOOD

Intraindividual variability is a fundamental phenomenon of aging: Evidence from an 8-year longitudinal study across young, middle, and older adulthood

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Abstract

Moment-to-moment intraindividual variability (IIV) in cognitive speed is a sensitive behavioural indicator of the integrity of the aging brain and brain damage, but little information is known about how IIV changes from being relatively low in young adulthood to substantially higher in older adulthood. We evaluated possible age group, sex, and task differences in IIV across adulthood using a large, neurologically normal, population-based sample evaluated thrice over 8 years. Multilevel modeling controlling for education, diabetes, hypertension, and anxiety and depressive symptoms showed expected age group differences in baseline IIV across the adult lifespan. Increase in IIV was not found until older adulthood on simple tasks, but was apparent even in the 40s on a more complex task. Females were more variable than males, but only at baseline. IIV in cognitive speed is a fundamental behavioural characteristic associated with growing older, even among healthy adults.

Key words: Intraindividual variability, inconsistency, adulthood, change, longitudinal

The length of time needed to respond to a stimulus, or reaction time (RT), consistently increases across adulthood (e.g., Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994). However, individuals not only become slower with older age, they also become more variable in their responding from one moment to the next, or from one RT trial to another. A number of cross-sectional studies have demonstrated that intraindividual variability (IIV) in cognitive speed, or inconsistency, shows a U-shaped curve across the lifespan (6-89 years, Li et al., 2004; 6-81 years, Williams, Hultsch, Strauss, Hunter, & Tannock, 2005; 5-76 years, Williams, Strauss, Hultsch, & Hunter, 2007), and is greater among older than younger adults (e.g., Hultsch, MacDonald, & Dixon, 2002) even when controlling for group differences in mean response speed and practice effects.

Further, inconsistency in cognitive speed appears to be maladaptive in older age. Greater variability has been associated with poorer levels of performance on a range of cognitive tasks and intelligence (e.g., Rabbitt, Osman, Moore, & Stollery, 2001), poorer physical performance (Anstey, 1999; Li, Aggen, Nesselroade, & Baltes, 2001), less activity participation (Bielak, Hughes, Small, & Dixon, 2007), poorer performance on tests of everyday functioning (Burton, Strauss, Hultsch, & Hunter, 2009), and poorer mental health (Bunce, Handley, & Gaines, 2008). Patients with various types of neurological trauma or disease have been found to show greater IIV than healthy older adults including those with Parkinson's disease (Burton, Strauss, Hultsch, Moll, & Hunter, 2006; de Frias, Dixon, Fisher, & Camicioli, 2007), dementia (Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Murtha, Cismaru, Waechter, & Chertkow, 2002), mild cognitive impairment (MCI) (Christensen et al., 2005; Dixon et al., 2007; Strauss, Bielak, Bunce, Hunter, & Hultsch, 2007), and traumatic brain injury (Stuss, Murphy, Binns, & Alexander, 2003).

Greater inconsistency in adulthood has also been linked to maladaptive structural, functional, and neuromodulatory brain characteristics (see MacDonald, Li, & Bäckman, 2009 for a review). For example, lower white matter integrity, including decreased volume and increased prevalence of hyperintensities, have been associated with increased IIV across adulthood (Anstey et al., 2007; Bunce et al., 2010; Bunce et al., 2007; Fjell, Westlye, Amlien, & Walhovd, 2011; Walhovd & Fjell, 2007). Studies using computational models (Li, Lindenberger, & Sikström, 2001) and positron emission tomography (MacDonald, Karlsson, Rieckmann, & Nyberg, 2012) also indicate that dysfunctional dopamine modulation is particularly linked to more behavioural IIV across adulthood. Overall, although the exact determinants of IIV are not clearly understood, there is considerable evidence demonstrating the neurological basis of IIV in adulthood.

Longitudinal studies have shown IIV covaries with cognitive performance across time (Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010b; Lövdén, Li, Shing, & Lindenberger, 2007; MacDonald, Hultsch, & Dixon, 2003), and baseline inconsistency predicts later attrition, mild cognitive impairment (Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010a; Cherbuin, Sachdev, & Anstey, 2010), and even death (MacDonald, Hultsch, & Dixon, 2008). Therefore, inconsistency in adulthood is believed to be a behavioural indicator of neurological integrity, where compromised integrity translates into less consistent responding on measures of cognitive speed (Hultsch, et al., 2000; Hultsch, Strauss, Hunter, & MacDonald, 2008).

IIV across the lifespan

Due to the possibility that IIV may be a marker of the integrity of the brain, the majority of studies have focused exclusively on older adulthood. There has therefore been little information about how inconsistency changes from being relatively low in young adulthood to substantially higher in older adulthood. Our aim in the present study was to provide a thorough

examination of how inconsistency changes across adulthood using a large, population-based sample evaluated over 8 years. Previous cross-sectional data covering the adult life-span has shown that IIV on a choice RT task appears to be at its lowest point in the late teens and 20s, before steadily increasing with age (Williams, et al., 2005; Williams, et al., 2007). A large cross-sectional study of adults aged 18-94 years found IIV on a simple RT task remained stable until approximately age 50, while IIV for choice RT increased linearly across age (Der & Deary, 2006). A similar trend was evident in the first wave of the present study under investigation, where only those between 60-64 years showed greater inconsistency than those between 40-44 years on a simple RT task, but a stepwise increase was found beginning in young adulthood for choice RT (Anstey, Dear, Christensen, & Jorm, 2005).

However, cross-sectional age differences do not always correspond to actual changes with age (e.g., cognitive decline, Salthouse, 2009; Sliwinski & Buschke, 1999). Does IIV increase over time even among those in their 20s, or is it stable until a certain age? Deary and Der (2005) tested approximately 500 adults aged 16, 36 and 56 years twice across a 8 year period on simple and choice RT tasks. Although they initially found inconsistency on both tasks increased linearly with age, after controlling for mean RT the age effects were dramatically reduced and differences between the cohorts disappeared. Fozard and colleagues (1994) examined a similar number of adults aged 20 to 90 years and noted a significant age-related increase in variability in responding to an auditory choice RT task over 4 years, but did not further describe the nature and shape of the increase. In an investigation over 6 years, MacDonald and colleagues (2003) found only those between 75 and 89 years showed significant increases in IIV, while those between 55 and 64 years and between 65 and 74 years remained stable or decreased slightly. Results from other longitudinal studies focusing exclusively on older adults confirm an increased acceleration in old-old adulthood (i.e., after 75 years of age, Bielak, et al., 2010b; Lövdén, et al., 2007). Overall,

given the conflicting findings in older age, and the limited studies focusing on the earlier half of adulthood, it is unclear what the longitudinal inconsistency relationship looks like in young and middle adulthood.

Gender effects

Another unknown factor is whether sex plays a role in age-related IIV change. Females have been reported to be slower in responding to RT tasks than males (Fozard, et al., 1994; Jorm, Anstey, Christensen, & Rodgers, 2004), and also show more variability in responding to a choice RT task across adulthood (Der & Deary, 2006). Others have found this sex difference in IIV might only be present for those in their 30s and mid adulthood, but not among those in their late teens and 20s (Deary & Der, 2005). However, Reimers and Maylor (2006) have suggested this difference might actually be an artifact of failing to account for trial effects. They found females were slower than males only on the initial trials of responding, but became faster than males across the RT task. When the initial trials were excluded, the sex difference in inconsistency disappeared. Therefore, it is unknown whether males and females truly differ in their inconsistency in cognitive speed.

Cognitive load and IIV

Finally, both age and sex differences in IIV might also vary by the complexity of the reaction time task. In a 3 year longitudinal study of over 300 participants aged 64 to 92 years, Bielak and colleagues (2010b) found individuals older than 75 years of age showed significantly greater annual increases in inconsistency for measures derived from choice RT and task-switching RT tasks, but not for inconsistency from a simple tapping RT task. Other examples of similar task-related group differences in IIV abound in the literature, where larger effects have been found for tasks drawing on executive processes such as inhibition, task switching, or working memory (e.g., Dixon, et al., 2007; MacDonald, et al., 2003; West, Murphy, Armilio,

Craik, & Stuss, 2002). Consequently, the pattern of change in inconsistency across time may differ based on task complexity, and affect the detection of age and sex differences.

In the present study, we evaluated change in IIV across 8 years in a population-based sample of 3 different age cohorts, who at baseline were between 20-24 years, 40-44 years, and 60-64 years. This unique longitudinal study provided an excellent design through which to examine possible age group, sex, and task differences in inconsistency throughout the adult lifespan. We investigated whether there were significant age group, sex, and age group by sex differences in the starting value of and change in IIV on two different RT tasks over 8 years. Because past research on both age and sex differences in IIV conflict, we limited our hypotheses to the predictions that inconsistency would increase with age, and that age differences would be greater on a more cognitively challenging RT task. Finally, because higher IIV has been linked to poorer cognitive performance and various medical conditions (Bunce, et al., 2008; Whitehead, Dixon, Hultsch, & MacDonald, 2011), we controlled for education, diabetes, hypertension, and anxiety and depressive symptoms.

Method

Data were drawn from the PATH Through Life Project (PATH), a longitudinal study whereby participants from 3 different age cohorts (i.e., 20s, 40s, and 60s) are repeatedly tested every 4 years (see Anstey et al., 2011). The current analyses use three waves of testing (i.e., over 8 years).

Participants

PATH participants are community-dwelling adults residing in the city of Canberra or the neighbouring town of Queanbeyan, Australia. Potential participants included those aged 20-24 years on January 1, 1999, 40-44 years on January 1, 2000, and 60-64 years on January 1, 2001. Participants were recruited through the electoral rolls, for which registration is compulsory for

Australian citizens. The number of participants who returned the survey totaled 7, 485, of whom 2,404 were in the 20s, 2,530 in the 40s, and 2,551 in the oldest cohort. Approximately half of each age cohort was female.

There was limited sample attrition 4 and 8 years later, as 6,680 and 5,996 participants completed Waves 2 and 3, respectively. Participants were excluded from the present analyses if they reported having a history of stroke, significant head injury, epilepsy, Parkinson's disease, or brain tumor, and older participants who scored less than 24 on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) at any time point. Participants had to have valid data for all covariate measures and sufficient RT data (see intraindividual variability section), resulting in a final sample of 6562 participants. The mean length of follow-up among participants was 6.91 years (SD = 2.54). Further descriptive information about the sample is presented in Table 1.

Measures and procedure

At each wave, participants answered a questionnaire that assessed their sociodemographic characteristics, and completed measures of well-being, mental and physical health, and cognitive functioning. The majority of the assessment was administered on a hand-held or laptop computer, and was completed under the supervision of and with the assistance of a trained interviewer (for further details see Anstey, et al., 2011).

Intraindividual variability.

Intraindividual variability was calculated from the response latencies on two reaction-time tasks, each administered once per testing wave. Both tasks were completed using a small box which served as both the response console and the display area. The box was held with both hands, with left and right buttons at the top to be depressed by the index fingers. The front of the box had three lights: two red stimulus lights under the left and right buttons respectively and a

green get-ready light in the middle beneath these. The simple reaction-time (SRT) task was completed first, immediately followed by the choice reaction-time (CRT) task. In SRT, participants were presented with a green get-ready light, followed by the right red light after varying amounts of time. Participants were asked to press a button as soon as the red light appeared. For each CRT trial, participants were presented with the green get-ready light. After varying amounts of time, one of the two red lights illuminated and participants were asked to press the corresponding response button as soon as possible. There were 40 trials presented for CRT, and 80 for SRT.

Covariates.

We chose to control for the effects of education, diabetes, hypertension, and anxiety and depressive symptoms. *Education* was assessed by years of formal schooling (M = 14.86, SD = 2.31), and *diabetes* was based on the self-reported presence of the disease at any wave (5.7% of sample). *Hypertension* was determined from blood pressure readings administered by testers at each wave, and any participant scoring above 140 systolic or 90 diastolic, or reporting taking blood pressure medication at any wave was coded as having hypertension (48.2% of sample). *Anxiety* and *depressive symptoms* were based on responses to the Goldberg Anxiety and Depression Scale (Goldberg, Bridges, Duncan-Jones, & Grayson, 1988), and were entered into the models separately as time-varying anxiety and depression scores.

Data preparation and calculation of intraindividual variability

The data preparation and intraindividual variability procedures were completed separately for each task at each wave. Individuals who did not complete more than 50% of the trials[1] for each task were removed from the IIV calculation for that wave. First, incorrect CRT responses

[1] A significant reduction in the accuracy of imputation has been shown above 50% of item-level missingness (Burns et al., 2011).

were removed to ensure that IIV was not the result of slower wrong responses. The remaining RT latencies for both tasks were then trimmed for outliers. Lower limit trims included removing any trials below 50ms for SRT, and below 150ms for CRT. Means and standard deviations were next calculated for each individual across all trials, and any latencies that exceeded +3SDs for that individual were deleted[2]. Missing values were imputed using a regression substitution procedure, whereby individual regression equations across all trials for each task were formed and used to predict the missing values (Hultsch, et al., 2000). This approach reduces within-subject variation and represents a conservative approach to estimating inconsistency. Approximately 4% of trials were subjected to the imputation procedure.

The calculation of IIV was in accordance with methodology developed by Hultsch and colleagues (2000). In order to account for potential confounding influences in the RT data (e.g., age differences in mean RT, practice effects), the trial RT data was regressed onto categorical age group, categorical trial, and their interactions (see Hultsch, et al., 2008 for a description of statistical considerations). This effectively removed mean RT trends from the data. The resulting residuals were then converted to standardized *T*-scores and each individual's SD across all trials was calculated. The individual standard deviation (ISD) was used as the indicator of intraindividual variability. ISD values were computed for each task at each wave (see Supplementary Table 1). As a further evaluation of this calculation strategy, we found the additional residualization of individual mean RT trends (i.e., within-person linear trial effects), followed by the removal of the mean age group and trial effects produced essentially identical

[2]A previous trimming of the Wave 1 SRT and CRT data for the 60s age group accidentally, but permanently, deleted the trials that exceeded the trim cutoffs. We employed a different trimming procedure and had to apply our method to the existing data after that event. Thus, the trimming procedure varied slightly for the Wave 1 60s cohort relative to the other cohorts and waves.

ISD values to our initial calculation approach (r = .999; see supplementary Appendix A for the statistical equations used in this additional calculation).

Statistical analyses

The ISD data were analyzed using multilevel models which allow the estimation of individual differences rather than only group differences as in multiple regression. These models also permit the inclusion of cases with incomplete data, and do not require equal spacing between waves. Because not all participants were tested at precise 4-year intervals, ISD change was modeled using a time in study metric. ISDs from the two RT tasks were evaluated separately. Age group, sex, and age group X sex were included as fixed predictors of the intercept. Models which included sex predicting the slope were not significant and did not significantly add to the model fit for either task; therefore only age group was a fixed predictor of the slope in the final model. The covariates education, diabetes, and hypertension were included as time-invariant predictors of the intercept, and anxiety and depressive symptoms were included as time-varying predictors. Random effects for the intercept and slope were estimated for both tasks (see supplementary appendix B for the statistical equations used), but initial models for SRT indicated a modest random slope variance (Estimate = .007, SE = .002, $p<.01$). Further models for SRT failed to converge, and thus the presented results for SRT do not include random slope. The results from the unconditional and full models with all factors and covariates included are presented in Table 2.

Results

ISD change - SRT

There were significant age group, sex, and Age group x Sex interaction effects for baseline ISD on the SRT task. For all three age cohorts, females tended to have higher ISD intercepts than males (20s, β = .42, SE = .10, $p<.001$; 40s: β = .33, SE = .10, $p<.01$; and 60s: β =

.72, SE = .10, p<.001). Although the age group differences were also similar across the sexes, it appeared that the size of these differences varied by sex. In the 60s cohort both males (M = 6.40) and females (M = 7.12) showed a higher average starting value than their respective 20s cohort groups (males: M = 5.14; β = -1.26, SE = .12, p<.001; females: M = 5.56; β = -1.56, SE = .12, p<.001), but this age difference was significantly larger for females (β = .30, SE = .14, p<.05). Further, the difference between the 40s (M = 6.15) and 60s males, albeit significant (β = -.25, SE = .11, p<.05), was less pronounced than for the female 40s (M = 6.48) versus 60s comparison (β = -.64, SE = .11, p<.001; age group x sex comparison: β = -.39, SE = .14, p<.01). Finally, those in their 40s also showed a higher baseline ISD than those in their 20s (females: β = -.92, SE = .11, p<.001; males: β = -1.01, SE = .12, p<.001), but this age comparison did not significantly differ by sex. Initial models showed a significant amount of between-person variance in intercept (estimate: 3.92, SE = .11, p<.001). When age group was entered into the model, there was a 19.7% reduction in this intercept variance.

Regarding change over time in study, the oldest cohort showed an average increase in their inconsistency over time (β = .17, SE = .01, p<.001), while the 40s and 20s age groups both showed slight decreases (20: β = -.06, SE = .01, p<.001; 40: β = -.06, SE = .01, p<.001; see Figure 1). Although the 60s group was significantly different from the two younger groups regarding change over time (both p<.001), the 20s and 40s groups did not differ from one another.

ISD change - CRT

The effects for baseline CRT were similar to those for SRT, but generally lacking sex differences, and the Age group x Sex interaction. Only the average female in her 20s (M = 5.93) was more inconsistent at baseline than the average male of the same age (M = 5.68; β = .25, SE = .07, p<.01). Regarding cohort differences, the pattern was as expected with both sexes in the 60s

cohort showing the highest average baseline ISD (females: M = 7.85; males: M = 7.78) compared to the average person of the same sex in their 40s (females: M = 6.70; β = -1.09, SE = .08, p<.001; males: M = 6.76; β = -1.07, SE = .08, p<.001), and 20s (females: β = -1.93, SE = .09, p<.001; males: β = -2.10, SE = .09, p<.001), and females and males in their 40s having a higher ISD than the 20s group (females: β = -.83, SE = .08, p<.001; males: β = -1.02, SE = .08, p<.001). Initial models showed a significant amount of between-person variance in intercept (estimate: 2.62, SE = .07, p<.001), and that the entry of age group into the model accounted for 33.6% of this intercept variance.

Figure 1 shows that the two oldest cohorts both showed average increases in their inconsistency over time (60s: β = .16, SE = .01, p<.001; 40s: β = .06, SE = .01, p<.001), but the 20s cohort did not significantly change over time. However, all three groups significantly differed from one another regarding change over time (all p<.001; see Table 2). Initial models showed there was a significant, yet modest amount of between-person variation in slope (estimate = .01, SE = .001, p<.001). Progressive model building showed that age group accounted for 85% of this slope variance.

Discussion

The main finding of the present study is that increases in IIV are a fundamental behavioural characteristic associated with growing older, even among healthy adults. There is sufficient evidence to confidently designate IIV in cognitive speed a developmental phenomenon, where IIV gradually increases across the adulthood lifespan, showing significant change even in mid adulthood.

Age group effects

We found a stepwise age group difference in baseline IIV on both simple and choice RT, where those in their 60s were more inconsistent than those in their 40s, and, in turn, those in their

40s were more inconsistent than those in their 20s. These results are in line with previous cross-sectional work (Hultsch, et al., 2002; Li, et al., 2004; Williams, et al., 2005; Williams, et al., 2007). Although Der and Deary (2006) and Anstey et al. (2005) found the same pattern cross-sectionally for IIV on choice RT, both found a relatively flat relationship up until age 50 or 60 for IIV on simple RT. The use of multilevel models in our study allowed the intercepts to vary by individual, possibly providing further variance and accuracy to our estimates. Overall, it appears that baseline inconsistency increases across adulthood, regardless of the complexity of the RT task.

The pattern is slightly different regarding actual change across time. For the simple RT task, only the oldest cohort showed a positive slope in IIV across the 8 years, with the two younger groups both slightly decreasing in IIV over time. In contrast, for choice RT the 40s age group became slightly more inconsistent with age, and the 60s age group showed even larger increases in variability. However, those in their 20s still did not significantly change over time. Previous research has shown the increases in IIV on moderately complex RT tasks (i.e., 2- and 4-choice RT) and highly complex RT tasks (i.e., 4-choice 1-back RT and 2-choice switch RT) to be greater with each additional year past age 75 (Bielak, et al., 2010b). Together with our present results, this suggests that on RT tasks that involve some cognitive complexity (i.e., other than a simple RT task), adults aged 40 and up show significant increases in variability over time, with the magnitude of the gain also increasing with greater age (i.e., 60s). However, MacDonald et al. (2003) found 6-year increases in IIVs for only those between 75 and 89 years at baseline, and slight decreases or stability for those between 55 and 64 years, and between 65 and 74 years, even for cognitively challenging RT tasks (i.e., lexical and semantic decision). Therefore, further longitudinal data across the entire range of adulthood is needed.

Although the size of the change that occurred over 8 years was relatively small, the change in CRT IIV was almost entirely accounted for by age group (a random slope parameter could not be estimated for SRT). The substantial influence of age is precisely what one would expect to find if increases in IIV are indeed a developmental phenomenon associated with non-pathological aging. Further, the size of the changes with each additional year would not be expected to be very large given the size of the differences between the age groups at baseline (e.g., those in their 40s cannot increase at a rate that would have them reach the baseline level of the 60s cohort well before their 60th birthday). Therefore, the size of the changes in IIV with age must be commensurate with the size of the age differences on the task itself amongst healthy adults. In addition, given demonstrations that IIV change covaries with cognitive change (e.g., Lövdén, et al., 2007), any shifts in IIV should correspond with the size of the cognitive change expected for that age group. This differential change aligns with our findings that IIV changes were most prominent for the oldest cohort, who experience a greater rate of cognitive change than younger adults (e.g., Salthouse, 2009). However, it appears that IIV change in simple RT may not follow the same rules. Rather, purely process-based IIV may operate on a step-wise rather than constant function in early and middle adulthood (i.e., with jumps eventually showing individuals performing at levels consistent with their new age group), and not show consistent developmental increases until older adulthood.

Given that maladaptive IIV is believed to be a sensitive behavioural indicator of neurological integrity, it is intriguing that increases in CRT inconsistency over 8 years were seen even among those aged 40-44 years at baseline. On the other hand, the slow decline of various cognitive abilities across adulthood, particularly processing speed, is well documented (Salthouse, 2009). In fact, Bunce and colleagues (2010) found an association between IIV and

frontal white-matter hyperintensities in a cohort subsample from the same sample, further demonstrating that neurological integrity may be compromised well before older age.

Sex, and Age group X Sex interaction effects

We also found evidence of sex differences in IIV, but only in relation to the baseline level and not change over time. For inconsistency on the simple RT task, females had higher intercepts than males across all three age groups, and age differences were more pronounced among females. The sex differences were reduced for choice RT, where only females in the youngest age group were more inconsistent than males of the same age. Our analyses controlled for trial effects, and thus do not support Reimers and Maylor's (2006) suggestion that sex differences in inconsistency are only the result of females' slower responding on the initial trials. Although the direction of the sex difference is the same, our findings are in contrast to past work finding the strongest sex effect for choice RT and no differences for simple RT (Der & Deary, 2006), and showing only females aged 36 and older had more variability than males, and only on choice RT (Deary & Der, 2005).

Although the explanation as to why females were more variable at the first wave of testing is unclear, the fact that this was only found for simple RT and not choice RT is intriguing. The simple RT task was completed before the choice RT task, and it may be that aspects of the testing situation influenced females (e.g., test anxiety) more than males during the simple RT task, but these factors then diminished during the second RT task. Further, because past research has consistently found larger IIV group differences on RT tasks that pose a greater cognitive challenge (e.g., West, et al., 2002), the fact that the same was not found in relation to sex suggests that the sex-related difference is not substantially related to differences in neurological integrity. For example, it is for groups that are believed to have poorer neurological integrity relative to their comparison group where task complexity differences have been found, such as those with

mild cognitive impairment (Dixon, et al., 2007). Further, because there was no evidence that males and females show different change in IIV across time, the presence of the intercept difference is likely not of neurological interest.

Given the interest in comparing IIV to mean RT (Hultsch, et al., 2008) we additionally evaluated the size of the model-implied change in mean RT for both tasks across the 8 years. The trials were converted to T-scores before calculating individual mean RT, thus permitting comparison with the ISD slope parameter estimates. For SRT[3], the 60s cohort showed an average increase in mean RT over time (60s: $\beta = 2.10$), but the two younger cohorts showed significant decreases (20s: $\beta = -1.49$; 40s: $\beta = -.43$). The results were similar for CRT[4], with the 60s cohort having slower average responding over time ($\beta = .78$) and the 20s responding faster ($\beta = -.33$), but the 40s cohort showing no significant change. Therefore, the general pattern of age-related differences in change is comparable to that observed in IIV. However, the change per year is greater for mean RT. Thus, although there has been evidence that IIV and mean RT might be fundamentally distinct phenomena (Burton, et al., 2009; Lövdén, et al., 2007), both appear to change relatively similarly across adulthood.

Despite the strengths of the present study, including a population-based sample, the large number of study participants and the longitudinal design, some limitations must be considered. First, there were only two indicators of IIV, both derived from relatively simple psychomotor tasks. Analyses on inconsistency computed from higher-order or more cognitive challenging RT tasks may demonstrate a different pattern of change. However, given past findings regarding task complexity (Bielak, et al., 2010b), the pattern using such tasks is predicted to be even stronger, with more pronounced age differences. Next, although the sample represented three distinct age

[3] There was sufficient variation in mean RT change to estimate a random slope parameter.
[4] There was insufficient variation in mean RT change, and a random slope parameter could not be estimated.

cohorts and provided an estimate of change across young, middle, and older adulthood, the spread in the age groups prevented a continuous estimate across adulthood. Relatedly, we also were limited to examining relatively early old age, and IIV change has been shown to be even greater in the later stages of older adulthood (Lövdén, et al., 2007). Further, the greatest change occurred between wave 1 and wave 2 for all age groups, with slight group-based decreases in IIV from waves 2 to 3. Although this pattern implies a quadratic function, we were unable to include this without model saturation. However, proportionally larger increases in IIV with age were still evident, reiterating the model-implied conclusion that IIV in processing speed change is a developmental phenomenon that increases in magnitude with age. Our multilevel models also permitted individual variation in the intercept (and the slope for CRT), and can provide greater insight than relying on group-based change from descriptive data. The decrease in IIV was likely the result of practice effects, with the 20s and 40s cohorts showing the greatest benefit. A fourth wave of data collection will clarify the longitudinal changes by permitting evaluation of IIV change from 20-36 years, 40-56 years, and 60-76 years of age. Finally, it remains a possibility that a portion of age-related changes in IIV could be due to age differences in strategic response behavior (i.e., the diffusion model) (Ratcliff & McKoon, 2008).

The present study aimed to fill a gap in the knowledge base on how moment-to-moment IIV in cognitive performance changes across adulthood. It appears that increases in IIV are a fundamental phenomenon associated with growing older, even among healthy adults. The magnitude of the increase depends on the task, with IIV on simpler tasks not increasing until older adulthood, and IIV on more complex tasks showing increases as early as middle adulthood. Given the documented predictive prowess of IIV in forecasting changes in neurological integrity (e.g., Bielak, et al., 2010a; MacDonald, et al., 2008), a shift towards greater attention to increases in inconsistency as markers of biological and cognitive aging, even in mid-life, is warranted.

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Table 1. Descriptive information about the sample covariates.

	Age group					
	20		40		60	
	Male	Female	Male	Female	Male	Female
	n = 1018	*n* = 1175	*n* = 1034	*n* = 1220	*n* = 1045	*n* = 1070
Measure	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Years of education	15.34 (1.73)	15.56 (1.72)	15.19 (2.22)	14.86 (2.29)	14.55 (2.65)	13.63 (2.57)
Anxiety at baseline	3.13 (2.59)	4.40 (2.68)	3.24 (2.62)	3.67 (2.70)	1.81 (2.12)	2.44 (2.35)
Depressive symptoms at baseline	2.55 (2.30)	3.16 (2.42)	2.23 (2.28)	2.51 (2.42)	1.42 (1.71)	1.69 (1.85)
% Diabetic	0.7	1.3	4.6	3.7	14.7	9.9
% Hypertensive	36.1	9.1	55.7	34.6	82.9	76.7

Note. SD = Standard deviation. Hypertension was defined as scoring above 140 systolic or 90 diastolic, or reporting taking blood pressure medication at any wave.

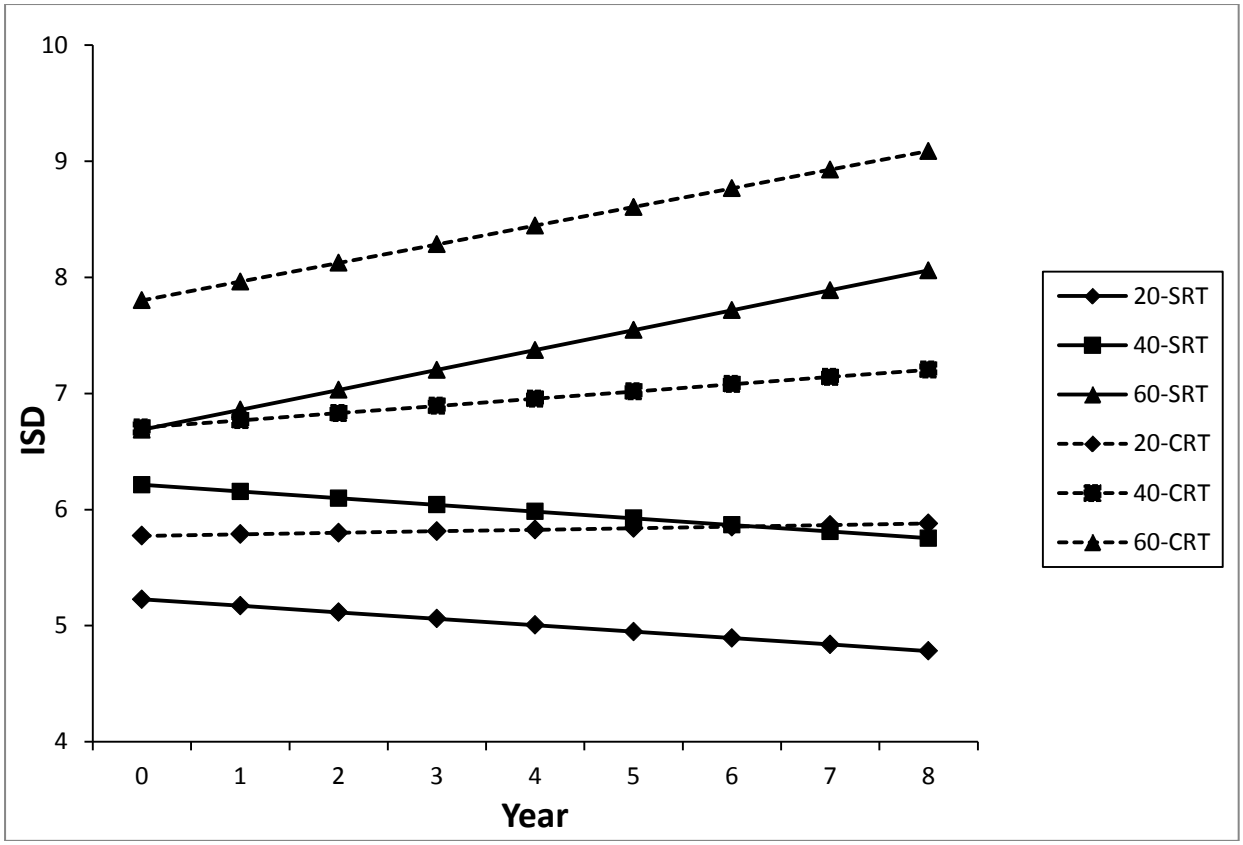
Table 2. Parameter Estimates from Multilevel Models Examining Age Group and Sex Differences in Intraindividual Standard Deviations (ISD) Across 8 Years.

	ISD			
	SRT		CRT	
Parameter	Estimate	SE	Estimate	SE
Unconditional Model (df = 3)				
Fixed effects				
Intercept	5.89***	.03	6.82***	0.02
Random effects				
Intercept variance	3.91***	.11	2.72***	.07
Residual variance	5.45***	.08	2.53***	.04
-2LL	84132		71126	
AIC	84138		71132	
Final Model				
Fixed effects				
Intercept	6.40***	.13	7.78***	.10
Time	.17***	.01	.16***	.01
Age Group contrasts				
60 vs. 20	-1.26***	.11	-2.10***	.09
60 vs. 40	-.25 *	.11	-1.07***	.08
40 vs. 20[a]	-1.01***	.11	-1.02***	.08
Sex	.72***	.10	.07	.07
Age Group x Sex contrasts				
60 vs. 20 x Sex[a]	.30*	.14	-.17	.10
60 vs. 40 x Sex	-.39**	.14	-.02	.10
40 vs. 20 x Sex[a]	.09	.14	.19	.10
Time x Age Group contrasts				
60 vs. 20	-.23***	.01	-.15***	.01
60 vs. 40	-.23***	.01	-.10***	.01
40 vs. 20[a]	.00	.01	-.05***	.01

Random effects				
Intercept variance	2.97***	.10	1.71***	.05
Slope variance	-		.001	.00
Residual variance	5.38***	.08	2.35***	.04
-2LL	82646 (df = 16)		68349 (df = 17)	
AIC	82678		68383	

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. SRT = simple reaction time; CRT = choice reaction time. 60s cohort, male, served as reference group. All estimates are unstandardized. Years of education, diabetes, hypertension, anxiety, and depressive symptoms were included as covariates in the final model. [a]Contrast tested in another analysis using same model but different coding for age group. Due to insufficient variation, random slope was not estimated for SRT in the final model.

Figure 1. Model implied change in ISD across time as a function of age group and task.



Note: ISD = Intraindividual standard deviation; SRT = Simple reaction time; CRT = Choice reaction time.

Supplementary Table 1. Descriptive Statistics of Valid Responses, Mean RT, and Intraindividual Standard Deviation by Task, Age Group, Sex, and Wave.

		Valid Responses*		Mean RT		ISD	
Age Group	*n*	SRT %	CRT %	SRT M (SD)	CRT M (SD)	SRT M (SD)	CRT M (SD)
Female							
20							
Wave 1	1002	96.2	96.9	223.50 (32.02)	267.59 (29.01)	5.35 (2.37)	5.54 (1.45)
Wave 2	1005	96.7	96.4	221.31 (31.17)	266.96 (30.12)	4.75 (1.96)	6.05 (1.81)
Wave 3	890	96.5	97.4	219.48 (30.29)	264.07 (30.46)	5.01 (2.05)	5.71 (1.66)
40							
Wave 1	1141	96.4	96.3	238.06 (41.46)	292.57 (39.82)	6.30 (3.42)	6.35 (1.79)
Wave 2	1111	96.9	96.1	244.28 (44.97)	298.09 (42.24)	5.73 (2.68)	7.16 (2.14)
Wave 3	1004	97.0	97.1	245.13 (50.58)	299.07 (43.36)	5.77 (2.75)	6.76 (1.87)
60							
Wave 1	1025	93.6	95.3	260.09 (59.78)	323.12 (54.63)	6.62 (3.54)	7.44 (2.26)
Wave 2	887	96.7	95.5	286.20 (75.72)	334.96 (55.35)	8.01 (4.55)	8.68 (2.67)
Wave 3	797	97.1	97.7	292.19 (67.84)	350.43 (59.13)	7.92 (3.90)	8.56 (2.47)
Male							
20							
Wave 1	895	96.4	96.4	213.49 (28.32)	260.88 (25.71)	4.95 (2.00)	5.33 (1.39)
Wave 2	845	96.6	96.0	211.51 (30.63)	260.88 (28.87)	4.35 (1.61)	5.77 (1.63)
Wave 3	733	96.2	97.1	206.18 (28.13)	254.84 (28.31)	4.31 (1.80)	5.28 (1.47)
40							
Wave 1	970	96.6	95.7	229.67 (66.97)	288.36 (92.51)	5.84 (2.64)	6.28 (1.66)
Wave 2	923	96.8	95.3	230.59 (37.34)	287.44 (35.91)	5.36 (2.40)	7.01 (2.16)
Wave 3	836	96.6	96.2	230.46 (38.97)	289.98 (38.02)	5.38 (2.30)	6.78 (2.06)
60							
Wave 1	1006	93.9	93.7	241.90 (49.01)	310.08 (42.45)	5.88 (3.07)	7.28 (2.02)
Wave 2	881	96.6	94.2	268.07 (72.43)	322.11 (49.91)	7.14 (3.73)	8.64 (2.67)
Wave 3	775	96.8	96.5	271.12 (68.79)	335.20 (53.26)	7.05 (3.28)	8.53 (2.40)

Note. Raw scores are presented. ISD = Intraindividual Standard Deviation; SRT = simple reaction time; CRT = choice reaction time. *Valid responses refer count after incorrect trials and outliers were removed, but before imputation.

Supplementary Appendix A

The additional evaluation of the ISD calculations to include partialling individual RT trends used the following regression equations:

Step 1: RT $score_i = a_i + b_i(trial) + e$

Step 2: Residualized RT score from Step 1 = a + b(age group) + c(trial) + d(age group X trial) + e

Step 1 removed the individualized mean RT trends (i.e., individual linear trial effects) for each individual (i). The residualized RT scores from Step 1 were then used in Step 2, which removed the group-based trial and age group effects. Given the potential confounding group influences in RT (i.e., age differences in mean RT), it was critical to additionally remove the group-based effects.

Supplementary Appendix B

The following statistical model was used:

Level 1: $ISD_{ij} = \beta_{0j} + \beta_{1j}(\text{Time in Study}) + \beta_{2j}(\text{Anxiety}) + \beta_{3j}(\text{Depressive symptoms}) + e_{ij}$

Level 2: $\beta_{0j} = \gamma_{00}(\text{Age group}) + \gamma_{01}(\text{Sex}) + \gamma_{02}(\text{Age group contrast}_1) + \gamma_{03}(\text{Age group contrast}_2) + \gamma_{04}(\text{Age group x Sex contrast}_1) + \gamma_{05}(\text{Age group x Sex contrast}_2) + \gamma_{06}(\text{Years of education}) + \gamma_{07}(\text{Diabetes}) + \gamma_{08}(\text{Hypertension}) + u_{0j}$

$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Age group contrast}_1) + \gamma_{12}(\text{Age group contrast}_2) + u_{1j}$

$\beta_{2j} = \gamma_{20}$

$\beta_{3j} = \gamma_{30}$

The Level 1 equation evaluated within-person change in ISD. Specifically, the change in ISD for a given individual (i) at a given occasion (j) was a function of that individual's ISD at the first wave of testing (β_{0j}), plus that individual's average rate of change in ISD across time in study (β_{1j}), rate of ISD change in relation to anxiety (β_{2j}), and rate of ISD change in relation to depressive symptoms (β_{3j}), plus an error term reflecting within-subject residual variance remaining to be explained after controlling for these variables (e_{ij}). At Level 2, or the between-subjects level, the intercept (β_{0j}) for each individual was modeled as a function of the starting point for the average participant in the reference age cohort (γ_{00}), and the starting point for the average participant of the reference sex (γ_{01}), plus the average difference in intercept between the reference age cohort and one age group (γ_{02}), plus the average difference in intercept between the reference age cohort and the other age group (γ_{03}), plus the average differences in intercept between the reference age X sex group and other age X sex groups (γ_{04}, γ_{05}), plus the intercept for the average participant with 14 years of education (γ_{06}), with diabetes (γ_{07}), and with hypertension (γ_{08}), plus variation between individuals in intercept (u_{0j}). Each individual's slope estimate (β_{1j}) was a function of change for the average member of the reference age cohort per year increase of

being in the study (γ_{10}), plus the average difference in slope between the reference age group and one age group (γ_{11}), plus the average difference in slope between the reference age cohort and the other age group (γ_{12}), plus variation between individuals in slope (u_{1j}). The slope in relation to anxiety (β_{2j}) and depressive symptoms (β_{3j}) reflected the respective ISD change for the average participant per unit increase in anxious symptoms (γ_{20}) and depressive symptoms (γ_{30}).