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Selective Attrition and Intraindividual Variability in Response Time Moderate Cognitive Change

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Abstract

Objectives—Selection of a developmental time metric is useful for understanding causal processes that underlie aging-related cognitive change, and for the identification of potential moderators of cognitive decline. Building on research suggesting that time to attrition is a metric sensitive to non-normative influences of aging (e.g., subclinical health conditions), we examined reason for attrition and intraindividual variability (IIV) in reaction time as predictors of cognitive performance.

Method—Three-hundred and four community dwelling older adults (64-92 years) completed annual assessments in a longitudinal study. IIV was calculated from baseline performance on reaction time tasks. Multilevel models were fit to examine patterns and predictors of cognitive change.

Results—We show that time to attrition was associated with cognitive decline. Greater IIV was associated with declines on executive functioning and episodic memory measures. Attrition due to personal health reasons was also associated with decreased executive functioning compared to individuals who remained in study.

Discussion—These findings suggest that time to attrition is a useful metric for representing cognitive change, and reason for attrition and IIV are predictive of non-normative influences that may underlie instances of cognitive loss in older adults.

Keywords

intraindividual variability; cognition; aging; attrition; longitudinal change

When describing cognitive change in aging, Baltes and Nesselroade (1979) distinguished between nonnormative and normative developmental influences. Normative developmental influences on cognition affects most individuals and are closely associated with chronological age. In contrast, non-normative influences, such as select disease processes, do not affect all individuals and their influence can be quite diverse depending on the nature,

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timing and sequence of their occurrence. The capacity to identify and differentiate between normative and pathological age-related influences on cognitive change is, in part, a function of how developmental time is indexed (Stawski, Smith, & MacDonald, 2015). If pathological influences are present (e.g., dementia, cardiovascular disease) and produce a developmental progression that is different from age-graded trajectories, then age-based models will not provide an accurate description of change (e.g., accelerated cognitive decline preceding dementia diagnosis) and may obscure identification of important causes of cognitive change (Sliwinski & Mogle, 2008). Event-based time structures, centred on an event of interest (e.g., time to disease onset, time to death), have shown to be a useful tool in representing time and allowing for a more nuanced account of within person change than is simply captured by chronological age or time in study (Alwin, Hofer, & McCammon, 2006), particularly in describing the period of accelerated decline that precedes the onset of dementia (Laukka, MacDonald, & Bäckman, 2006; Sliwinski, Hofer, Hall, Buschke, & Lipton, 2003).

Selective attrition presents an important methodological concern that may underestimate cognitive decline in longitudinal studies (Siegler & Botwinick, 1979; Hultsch, Hertzog, Small, Donald-Miszczak, & Dixon, 1992), as well as being a potential marker of pathological influences on cognitive change. Nonnormative changes in aging, such as disease processes or other health-related events, might increase the likelihood of participant drop out and have a negative influence on cognitive function (Sliwinski et al., 2003). Selective attrition has been associated with decreased estimates of dementia following ischemic stroke (Desmond, Bagiella, Moroney, & Stern, 1998), positively biased results towards individuals with higher cognitive ability in a healthy sample (Mitrushina & Satz, 1991), and rapid and accelerated trajectory of memory decline (Sliwinski et al., 2003).

The association between cognitive functioning and attrition has been examined in the context of terminal decline. The terminal decline hypothesis predicts that there is an accelerated trajectory of cognitive deterioration that is directly related to proximity to death, and that individual differences arise because some individuals are in a terminal decline phase (Bäckman & MacDonald, 2006). The effects of selective attrition and terminal decline may be linked by the impaired functioning of the individuals who eventually drop out, which may partly be related to the effects of specific disease processes underlying terminal decline (Rabbitt, Lunn, & Wong, 2008). Sliwinski, Hofer, Hall, Buschke, & Lipton (2003) investigated the relationship between time to attrition and time to death with regard to cognition, and found that attrition effects remained after controlling for time to death. Conversely, the effects of proximity to death were completely eliminated by controlling for time to attrition, suggesting that processes underlying cognitive decline were better assessed using time to attrition. Some possible reasons for this finding include medical interventions that alter the natural course of disease processes and that may impact death effects more than attrition effects, or reactive effects from poor cognitive performance resulted in participant dropout. Alternatively, perhaps attrition represents a proxy for subclinical conditions such as cardiovascular disease (Sliwinski et al., 2003). The precise mechanisms that underlie attrition and how it operates on cognitive performance in older adults remain largely unexplored.

Intraindividual variability (IIV) measured within a single person on a single task and over multiple occasions (Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000, (MacDonald & Stawski, 2015) is associated with structural, functional and neuromodulatory brain correlates that underlie age-related cognitive change (for a review see MacDonald, Li, & Bäckman, 2009). IIV is greater in older compared to younger adults even after group differences in speed were controlled (Hultsch, MacDonald, & Dixon, 2002). Increasing variability that accompanies aging is also associated with concurrent impairment on measures of perceptual speed, working memory, episodic memory and crystallized abilities (Hultsch et al., 2002). Systematic research suggests that this type of IIV reflects an important marker of aging-related cognitive decline as well as pathological changes in the brain (e.g., neurodegenerative disorders, traumatic brain injury; MacDonald et al., 2009). Increased variability has been shown to uniquely predict neurological status independent of mean-level performance, and may reflect an indicator of deteriorating neural mechanisms and deficits in central nervous system (CNS) functioning (e.g., Hultsch et al., 2000; MacDonald et al., 2009). A series of analyses over a 5-year period showed that higher average IIV in response speed across four waves of measurement significantly predicted attrition from the study (Bielak, Hultsch, Strauss, MacDonald & Hunter, 2010). Given the association between increased IIV and neurological problems, attrition appears to represent a close proxy for imminent health conditions.

Building on these findings, the present investigation has two primary objectives. First, we examined time to attrition as a developmental time metric sensitive to cognitive change. Although alternative time metrics (e.g., chronological age, time in study) could be examined, we specifically focused on time to attrition based on *a priori* hypotheses that attrition status reflects nonnormative aging influences and will be associated with a greater rate of decline (Sliwinski et al., 2003; Bielak et al., 2010). Second, we examined IIV and reason for attrition as reliable predictors of cognitive change. We hypothesize that greater IIV will be associated with greater decline in cognition and that individuals who withdrew from the study for memory or health-related reasons will show greater cognitive decline than those who completed the study.

Method

Project MIND (Mental Inconsistency in Normal aging and Dementia) is a longitudinal study designed to measure short-term inconsistency that reflects moment-to-moment or day-to-day fluctuations in cognitive performance, as well as long-term change in abilities and skills associated with aging. A complete methodological account of Project MIND has been described in detail elsewhere (Strauss, Bielak, Bunce, Hunter, & Hultsch, 2007) and thus, only sections relevant to this study will be summarized here.

Participants

The sample is composed of 304 community-dwelling Caucasian older adults (208 women and 96 men) between 64 and 92 years ($M = 74.02$, $SD = 5.95$) who were concerned about their cognitive functioning, but not diagnosed with any neurological disorder. Participants were recruited through advertisements in the local media (newspaper and radio).

Exclusionary criteria included physician-diagnosed dementia or a Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) score less than 24, a history of significant head injury (e.g., loss of consciousness greater than 5 minutes), other neurological or major medical illnesses (e.g., Parkinson's disease, heart disease, cancer), severe sensory impairment (e.g., difficulty reading newspaper-size print, difficulty hearing a normal conversation), drug or alcohol abuse, current psychiatric diagnosis, psychotropic drug use, and lack of fluency in English. Overall, participants were well educated (M = 15.15, SD = 3.14; range, 7-24 years), performed well on the MMSE (M = 28.74, SD = 1.23; range 24-30), and were relatively in good health (total number of chronic health conditions: M = 2.92, SD = 1.91; range, 0-10). Of the original sample, 72% completed the study, 12.2% did not return citing personal health and/or memory problems or died during the study period, and 15.8% did not return due to poor health of a family member, too busy, no longer interested, or could not be located. Descriptive statistics characterizing these three groups (returnees, attrition due to personal vs. family reasons) are reported in Table 1.

Procedure

Participants were initially screened for inclusion and exclusion criteria by a telephone interview. Baseline testing occurred across seven sessions (one group and six individual) scheduled over approximately 3 months. The group testing session was held at the university, and the individual testing sessions were conducted in the participant's home. Participants provided demographic and health information, and completed cognitive measures in two testing sessions (one group and one individual). At baseline assessment, participants completed five biweekly individual sessions varied across days of the week and times of the day, during which they completed various reaction time tasks. The entire testing battery was repeated annually four times, totalling five waves of data. Due to changes in data collection procedures, select tests (i.e., Trail Making Tests, Block Design) were not administered in the final year of the study. For each subsequent year of testing, four (rather than five) biweekly testing sessions were completed. The tasks across all the testing sessions were identical. Baseline assessments began in 2001, and participants underwent annual evaluations of cognitive status. The last complete assessment occurred in 2006-2007.

Cognitive Measures

Perceptual speed—Participants' perceptual speed was measured using Trail Making Tests, Part A and B (Reitan & Wolfson, 1985). In Part A, participants were asked to connect numbers on a page in numerical order as quickly and accurately as possible. Part B places greater demands on executive functioning by requiring participants to connect numbers and letters in alternating sequential order (e.g., 1-A-2-B-3-C...). Time to task completion on Part A and B were used as outcome measures.

Episodic Memory—We assessed episodic memory by participants' immediate free recall of 30 words (Hultsch, Hertzog, & Dixon, 1990). The word list consisted of six taxonomic categories (5 words per category). Participants were required to study the words for two minutes and then asked to write down as many words as possible in five minutes. The number of correctly recalled words was recorded.

Reasoning—Block Design subtest from the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) was used to assess reasoning abilities. On this task, participants were asked to arrange colored blocks according to a presented design. A score out of 68 based on accurate and timely completion of the design was used as the outcome measure.

Vocabulary—Participants were required to select the correct definitions of English words on a 36-item multiple choice test (Ekstrom, French, Harman, & Dermen, 1976). Participants were given eight minutes to complete the task and the total number of correct items was used as the outcome measure.

Reaction Time (RT) Measures

The RT measures were completed in five individual testing sessions scheduled approximately every two weeks distributed across days of the week and times of the day. During each session, participants completed a set of computer-based tasks as quickly and accurately as possible to assess reaction time to the nearest millisecond. The RT tasks were presented on a Panasonic CF-48 laptop computer (Intel Pentium III 800-MHz processor, MS-DOS operating system version 4.10.2222) with a 14″ color screen. The computer processor controlled stimulus presentation and timing for each RT task. Participants responded to stimuli by pressing keys on a custom-designed response console, comprised of 4 response keys in a linear array within an aluminum enclosure. This response box was interfaced with the laptop through a PCMCIA Game Port, directly accessible by the CPU, in order to ensure millisecond timing latency (+/− 1 ms). The RT tasks were programmed using C++ and run on MS-DOS. Relevant variables assessing RT are summarized below.

Choice reaction time (CRT)—The stimulus consisted of a row of four plus signs. After a delay of 1000 ms, one of the plus signs changed into a box and participants were instructed to press the key corresponding to the location of the box. A total of 10 practice trials followed by 52 test trials were administered. The measures used were the response latencies for the 52 test trials.

Choice reaction time 1-back (CRT-1)—This task used the same stimulus display as the basic CRT task. However, in this version of the task, participants were instructed to press the key corresponding to the location of the box on the previous trial as quickly as possible. A total of 10 practice trials and 61 test trials were administered. Because participants made no response on Trial 1, the response latencies of the remaining 60 test trials were used for analysis.

Task switching—The stimuli for this task consisted of geometric figures varying in shape (square, circle) and color (red, green). A task cue indicating the relevant stimulus dimension (shape or color) was presented 600 ms before the geometric figure stimulus and participants were instructed to press the appropriate corresponding key. In the case of an error, the word ‘error’ appeared for 500 ms. Three blocks of 50 trials were presented, each preceded by 10 practice trials. In the first block, participants were instructed to respond to the shape of the figure. In the second block, participants were instructed to respond to the color of the figure.

In the last block, the relevant response dimension (shape, color) varied randomly. The outcome measures used were the response latencies for each of the three trial types.

Data Preparation

Preparation of the RT data and statistical computation of individual standard deviations (ISDs) as a measure of IIV has been described in detail elsewhere (Strauss et al., 2007). ISDs were computed based on RT data across all task trials as previous findings demonstrate comparable patterns of results based on all trials vs. accurate trials (e.g., Burton, Strauss, Hultsch, Moll, & Hunter, 2006). In brief, ISDs were computed as a general index of each participant's performance spread about his or her mean RT across trials, controlling for mean-level differences (i.e., age group) and practice effects (i.e., trial). Baseline ISD scores were averaged across the five testing sessions for each task. For the purposes of the present study, two composite factors determined by principal components analyses (PCA), Basic ISD (i.e., color, shape and CRT tasks) and Complex ISD (i.e., one-back and switch tasks), were used to provide the most reliable measures of IIV (Bielak et al., 2010). The complex RT tasks that comprised the Complex ISD factor included components from the basic RT tasks (e.g., motor control), as well as additional novel aspects requiring more complex cognition. Thus, to examine the individual unique contributions of basic and complex RT tasks, the Basic and Complex ISD factors were grand mean-centred and entered in the model separately.

Statistical Analyses

Longitudinal data were analyzed using linear mixed or multilevel models, a statistical technique particularly well suited for evaluating individual differences in rate of cognitive change (Singer & Willett, 2003). This statistical approach allows for assessment of within-person change (Level 1) that, in the present study, describes change in cognitive performance as a function of time to attrition, and between-person differences (Level 2) that examines whether variance in the within-person change slopes is systematically related to IIV. Among the advantages of multilevel modeling, employing full information maximum likelihood (FIML) estimation permits analysis of all available data, including data points for individuals who subsequently drop out of the study. Thus, the full sample (n = 304) was used to index intercept (baseline) values, with all available assessments used to estimate change. Relative to repeated measures ANOVA, multilevel modeling permits more precise measurements of change (i.e., explicitly models individual differences in retest intervals across waves of testing) and permits more flexible parameterization of time. Because participants were contacted on an annual basis, attrition was defined as the midpoint between the last occasion of complete testing and the following testing point at which dropout from study participation occurred. For participants who completed the study, the event was defined as occurring three months after their last testing occasion. For those who died during the study, their date of death was considered as the date of attrition. Time to attrition was parameterized in years.

At Level 2, self-reported reason for attrition and IIV measures were included in the model to assess its influence on cognitive decline. We created two dummy codes: (1) attrition from the study due to personal health or memory problems or death vs. those who remained in the

study; (2) attrition from the study due to other external reasons (e.g., family, health problems, lack of time or interest, moved away or could no longer be located) vs. participants who remained in the study. Age at baseline and total years of formal education were also included to adjust for cohort effects and because they are known to be associated with cognitive performance (Kempen, Brilman, Ranchor, & Ormel, 1999; Mortensen & Gade, 1993). In accordance with earlier work (e.g., Hultsch et al., 2002; Strauss et al., 2007), participants were classified into two groups based on age at baseline: 1) a young-old group aged 64-74 years (n = 170, M = 69.67, SD = 2.74) and 2) an old-old group aged 75-92 years (n =134, M = 79.54, SD = 4.02). These age ranges were constructed to capture quantitative differences in performance that are observed in the older adult range.

As several cognitive tasks were considered, a conservative p-value threshold for significance was chosen at .01. All data analyses were performed with HLM Version 6.06 using full information maximum likelihood for parameter estimation.

Results

Multilevel models were structured to determine whether significant change occurred as a function of time to attrition (indexed in years):

$$\begin{aligned} &\text{Level 1:} \quad \text{Cognitive task}_{ij} = \beta_{0j} + \beta_{1j}\,(time \quad to \quad attrition) + e_{ij} \\ &\text{Level 2:} \quad \beta_{0j} = \gamma_{00} + u_{0j} \\ &\qquad\qquad \beta_{1j} = \gamma_{10} + u_{1j} \end{aligned}$$

Significant fixed-slope effects were observed with decline for Trails B and improvement for Block Design per each additional year closer to study attrition (Table 2). The significant random-slope effect for the time to attrition model indicates reliable between-person differences in cognitive change and provides impetus to examine potential moderators of these individual differences.

An initial multilevel analysis with reason for attrition entered in the model used the following equations:

$$\begin{aligned} &\text{Level 2:} \quad \beta_{0j} = \gamma_{00} + \gamma_{01}\,(\text{attrition1}) + \gamma_{02}\,(\text{attrition2}) + u_{0j} \\ &\qquad\qquad \beta_{1j} = \gamma_{10} + \gamma_{11}\,(\text{attrition1}) + \gamma_{12}\,(\text{attrition2}) + u_{1j} \end{aligned}$$

Results indicated that that those individuals who dropped out of the study due to personal health problems and memory difficulties performed poorer on cognitive tasks at baseline and exhibited a steeper rate of decline over time on Trails B in comparison to those individuals who remained in the study (Table 3). Specifically, attrition from the study due to personal health or memory problems was associated with an average increase of 12.05 seconds in Trails B completion time for each year closer to attrition.

Since there were reliable differences between individuals lost to attrition and those that remained in study that accounted for significant variance in the model, the attrition groupings were included in all further analyses. On the demographic variables, categorical

age at baseline was found to vary significantly between attrition groups and was also included as a covariate in all subsequent analyses. Because education as a continuous variable did not systematically vary between attrition groups and was not a predictor of change in cognitive performance (analyses not presented), it was excluded from further consideration.

A series of hierarchal linear models were run to examine the unique contributions of IIV on cognitive performance, while controlling for age group and reason for attrition. The following Level 2 equations were used:

$$\text{Level 2:}\quad \beta_{0j}=\gamma_{00}+\gamma_{01}(\text{age group})+\gamma_{02}(ISD)+\gamma_{03}(\text{attrition1})+\gamma_{04}(\text{attrition2})+u_{0j}$$
$$\beta_{1j}=\gamma_{10}+\gamma_{11}(\text{age group})+\gamma_{12}(ISD)+\gamma_{13}(\text{attrition1})+\gamma_{14}(\text{attrition2})+u_{1j}$$

The results of these multilevel analyses are presented separately for Basic ISD and Complex ISD in the model (Tables 4 and 5). Both normality and homoscedasticity assumptions of level-1 and level-2 residuals for models were satisfied. Skewness and kurtosis levels were below conventional thresholds for non-normality (skewness values < 2 and kurtosis values < 7; West, Finch, & Curran, 1995) for most outcome and predictor variables.[1] Greater IIV on basic and complex RT tasks, as characterized by higher Basic and Complex ISD scores, were associated with poorer cognitive performance on initial status, except for the Vocabulary task. Attrition due to personal reasons when compared with the reference group (i.e., returnees) also reliably predicted baseline performance on Block Design and Word Recall with Basic ISD in the model. With Complex ISD in the model, attrition for personal reasons predicted baseline performance on Block Design, Word Recall and Trails B.

In terms of rate of change, Word Recall was the only task that was significantly associated with Basic ISD, with greater IIV linked with faster decline per year closer to attrition on this task. When the Complex ISD factor was entered in the model individually and subsequent to the covariates, greater IIV was associated with a faster rate of cognitive decline on tasks of Word Recall and Trails B prior to attrition. Attrition due to personal reasons emerged as the only reliable Level 2 predictor, with slower performance over time on Trails B for both Basic ISD and Complex ISD models. On Trails B, individuals who dropped out of the study due to personal health or memory problems were on average 11.40 seconds slower in the Basic ISD model and 10.68 seconds slower in the Complex ISD model per each year closer to attrition.

Discussion

In this study, change in cognitive performance over time was modeled using time to attrition based on *a priori* hypotheses regarding attrition effects. The time to attrition model resulted in reliable between-person differences in cognitive performance that warranted further investigation of the potential moderators of these individual differences. Attrition from study is related to a notably different magnitude in the rate of cognitive change among older

[1]Due to evidence of skewness and kurtosis, the raw latency scores for Trails A and B were log transformed and subsequently modeled; the pattern of results was identical for the raw vs. log-transformed data.

adults, possibly reflecting subtle changes in health status (e.g., presence of subclinical cardiovascular disease; Sliwinski et al., 2003). In part, this pattern could be related to the two different sources of attrition: more normative reasons for drop out (e.g., family health problems, busy, moved, no longer interested) and nonnormative reasons (e.g., died, personal health problems, memory problems). By choosing chronological age as a metric of time, as often is the convention, important pathological influences that affect subsets of the aging population are neglected and thus, important factors that explain cognitive decline are overlooked. A recent comparative analysis of four time metrics in a dementia sample demonstrated that time-with-disease was the most efficient metric for describing cognitive change as compared to chronological age, time in study and occasion of measurement (MacDonald, Karlsson, Fratiglioni & Bäckman, 2011). In fact, time-with-disease provided the best model of change to characterize the nonnormative influences of dementia underlying cognitive decline.

Our findings suggest that reason for attrition is a significant moderator of cognitive performance. At initial status, those individuals who dropped out citing poor personal health and memory reasons performed lower on several cognitive measures assessing fluid reasoning (Block Design), executive functioning (Trails B), episodic memory (Word Recall), and semantic memory (Vocabulary), when compared to individuals who remained in the study. This finding is consistent with previous research indicating that individuals who attrite perform lower at baseline than their counterparts who complete the study (Hultsch et al., 1992). Overall, individuals who dropped out due to family health problems and other external reasons did not differ significantly on cognitive performance from those who completed the study, with the exception of Block Design and Word Recall. Bearing in mind that reason for attrition was self-reported, this latter finding may reflect the reality that this attrition group may contain both individuals who dropped out for external reasons and for personal health or memory problems. In addition, there may be unknown person-specific factors related to individuals who decide to drop out that are inherently different from those who choose to remain in the study (e.g., genetic factors, personality, lifestyle).

The effect of personal reasons for attrition on the rate of cognitive decline was evident on a task of speeded visuomotor tracking and alternating/switching attention (Trails B), which suggests that this facet of executive functioning is particularly vulnerable to the effects of pathological aging as indexed by attrition. In fact, many studies have reported that impaired performance on tasks of executive functioning in normal individuals can predict progression to Alzheimer's disease (AD; Blacker et al., 2007; Chen et al., 2000; Thorvaldsson et al., 2011). Our findings support the view that less pronounced cognitive impairment and mild health conditions in part underlie attrition effects and thus, attrition moderates cognitive performance on tasks that are sensitive to subsequent diagnoses of neurodegenerative processes.

With respect to IIV, our results suggest that both Basic and Complex ISD reliably moderate cognitive performance on initial status and on rates of cognitive decline. At initial status, greater Basic and Complex ISD were significantly associated with poorer performance on all cognitive tasks, with the exception of Vocabulary. This is not an unexpected finding, as vocabulary is considered a crystallized ability (Strauss, Sherman, & Spreen, 2006), and more

resistant to the effects of both normative and pathological aging. Regarding the rate of decline, greater IIV on basic RT tasks was associated with declining episodic memory (Word Recall), whereas greater IIV on complex RT tasks was associated with declining performance on both episodic memory (Word Recall) and executive functioning (Trails B) tasks. Although non-significant for the other cognitive tasks, the trend was in the expected direction, with the exception of Vocabulary in the Basic ISD model. Basic ISD represents tasks that tap into fundamental brain processes (e.g., perceptual and sensorimotor speed), whereas Complex ISD tasks require more involved cognition (e.g., cognitive switching) in addition to the basic mental processes. Thus, decline in Trails B performance was only observed when the RT tasks were more cognitively complex and assessed some similar components, requiring manipulation of information held briefly in mind, switching cognitive set or inhibiting an automatic response. In addition, performance variability has been observed to increase with age on tasks requiring executive control (West, Murphy, Armilio, Craik, & Stuss, 2002).

The finding that IIV moderates rate of decline on tests assessing episodic memory and executive functioning is consistent with the extant literature. Studies have found that greater IIV is associated with lower general intelligence (Li et al., 2004) and poorer performance on more specific cognitive domains (e.g., perceptual speed, working memory, episodic memory, fluid reasoning and crystallized abilities) at initial status and over time (Hultsch et al., 2002; West et al., 2002; MacDonald, Hultsch, & Dixon, 2003). If IIV reflects structural, functional and neuromodulatory alterations in the brain, our findings complement numerous others that suggest the cognitive domains of executive functioning and episodic memory are among the most vulnerable to these changes. Evidence from numerous studies examining AD prediction indicate that deficits on neuropsychological test performance, particularly those assessing episodic memory and executive functioning, are predicative of subsequent AD diagnosis (Bäckman, Jones, Berger, Laukka, & Small, 2005; Blacker et al., 2007; Chen et al., 2000).

There are some limitations of the study that need to be considered. First, it is important to note the healthy and highly educated status of our sample. This selection bias tends to produce a positive bias in research results, which may underestimate the degree of cognitive impairment and affliction of chronic illnesses experienced by the average older adult. Thus, the ability to generalize our findings to the broader population may be limited. Second, self-reported reason for attrition may mask the true reason for withdrawal from the study, such as failing health or memory difficulties that hinder their ability to participate, thus limiting the validity of the measure. Third, although our results showed significant prediction of performance on Trails B, executive function is a complex construct with multiple dimensions. It is unclear whether other indicators of executive functioning (e.g., inhibition, updating) would exhibit similar associations with variability. Finally, the direction of the mediation between IIV and cognitive measures is not clear from the present analyses – is variability an outcome or a cause of developmental change (Lindenberger & von Oertzen, 2006)? Some recent evidence suggests that changes in variability precedes and predicts changes in means (Lövdén, Li, Shing, & Lindenberger, 2007).

Our findings are consistent with the view that IIV is associated with CNS functioning, and may underlie the association between cognitive loss and selective attrition. IIV and reason for attrition were found to operate independently of one another, suggesting unique influences that each contribute to understanding cognitive function and change during old age. At a methodological level, our findings support recent views underscoring the importance of selecting an appropriate time metric based on theory and a priori hypotheses and that study attrition may reflect instances of nonnormative aging (Sliwinski et al., 2003). The issue of attrition effects are important, particularly in an aging population who as a group are more likely to experience health and memory concerns. Further directions for research include more refined markers of IIV with a more diverse sample, and further elucidation of the mechanisms of IIV using direct measures of brain and behavior.

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Table 1

Descriptive Statistics for Attrition, Baseline Neuropsychological, and IIV Variables

Variable	Returnees (*n* = 219)	Attrition (Personal) (*n* = 37)	Attrition (Family) (*n* = 48)
Time to Attrition, *years*	5.55 (.20)	3.09 (1.27)	2.63 (1.24)
Block Design	36.84 (10.11)	27.84 (8.46)	31.63 (8.69)
Word Recall	16.97 (3.97)	13.35 (5.06)	15.81 (3.98)
Trails A, *seconds*	38.86 (12.92)	51.48 (20.51)	41.57 (12.28)
Trails B, *seconds*	86.77 (30.07)	120.03 (61.43)	95.23 (37.67)
Vocabulary	30.41 (4.28)	27.89 (4.82)	29.50 (4.48)
Basic ISD	7.41 (1.71)	9.22 (2.21)	7.82 (1.78)
Complex ISD	7.32 (2.53)	8.82 (2.44)	7.99 (2.63)

Note. *M* (*SD*); ISD = intraindividual standard deviation.

Table 2

Multilevel Models as a Function of Time to Attrition on Five Cognitive Tests

	Block Design	Word Recall	Trails A	Trails B	Vocabulary
Fixed Effects					
Intercept	34.90**	16.82**	40.59**	90.84**	30.07**
Slope	0.31*	0.004	−0.35	1.73*	0.01
Random Effects					
Variances					
Level 2, Intercept (% total)	91.67* (84.54)	12.57** (71.22)	144.24** (65.04)	891.12** (62.37)	16.47** (87.14)
Level 2, Slope (% total)	1.46** (1.35)	.22** (1.25)	12.86** (5.80)	42.82** (3.00)	0.02* (0.11)
Level 1, *Residual* (% total)	15.30** (14.11)	4.86** (27.54)	64.68** (29.16)	494.85** (34.63)	2.41** (12.75)

Note. Slope and intercept coefficients for each cognitive test are reported in a *t*-score metric

* $p < .01$

** $p < .001$.

Table 3

Comparison of Attrition Group on Five Cognitive Outcomes.

Fixed Effects	Block Design	Word Recall	Trails A	Trails B	Vocabulary
Intercept					
Returnees	38.91** (0.83)	18.08** (0.29)	35.24** (0.79)	75.77** (2.00)	30.86** (0.31)
Attrition (Personal)	−7.13** (1.60)	−3.11** (0.84)	7.37 (3.60)	26.99* (9.94)	−2.04* (0.82)
Attrition (Family)	−4.52* (1.38)	−1.63* (0.61)	1.59 (1.93)	6.51 (4.97)	−1.18 (0.69)
Slope					
Returnees	0.51* (0.17)	0.16* (0.06)	−0.71 (0.29)	−1.10 (0.66)	0.05 (0.03)
Attrition (Personal)	−0.70 (0.55)	−0.42 (0.23)	3.93 (2.22)	12.05* (4.35)	−0.36 (0.18)
Attrition (Family)	0.002 (0.37)	0.16 (0.18)	1.07 (0.62)	0.95 (1.82)	0.10 (0.11)

Note. Slope and intercept coefficients for each cognitive test are reported in a *t*-score metric; Values in parentheses are standard errors

* $p < .01$

** $p < .001$.

Table 4

HLM Coefficients and Standard Errors for Age Group, Attrition Group, and Basic ISD on Cognitive Tests as a Function of Time to Attrition

	Block Design	Word Recall	Trails A	Trails B	Vocabulary
Fixed Effects					
Intercept					
Returnees	37.68** (0.88)	17.64** (0.30)	37.05** (0.91)	82.67** (2.15)	30.72** (0.36)
Age Group	−3.44* (1.21)	−0.66 (0.48)	6.34** (1.59)	12.62** (3.57)	−0.50 (0.55)
Attrition (Personal)	−4.95* (1.64)	−2.33* (0.83)	4.21 (3.45)	14.99 (7.82)	−1.80 (0.86)
Attrition (Family)	−4.08* (1.40)	−1.47* (0.60)	0.97 (1.79)	4.31 (4.54)	−1.13 (0.70)
Basic ISD	−1.43** (0.33)	−0.52** (0.14)	2.12** (0.47)	8.06** (1.32)	−0.16 (0.14)
Slope					
Returnees	0.42 (0.19)	0.08 (0.06)	−0.55 (0.31)	−0.65 (0.66)	0.03 (0.03)
Age Group	−0.24 (0.28)	−0.19 (0.10)	−0.50 (0.63)	2.56 (1.19)	−0.04 (0.06)
Attrition (Personal)	−0.60 (0.55)	−0.30 (0.23)	3.72 (2.13)	11.40* (4.29)	−0.33 (0.18)
Attrition (Family)	−0.02 (0.34)	0.15 (0.17)	1.12 (0.62)	0.92 (1.84)	0.10 (0.11)
Basic ISD	−0.11 (0.08)	−0.09** (0.03)	0.19 (0.17)	0.52 (0.33)	−0.03 (0.02)
Random Effects					
Variances					
Level 2, Intercept	69.56**	9.94**	100.04**	465.54**	15.53**
Level 2, Slope	1.35**	0.17**	10.87**	29.63**	0.01*
Level 1, *Residual*	15.26	4.83	65.18	486.87	2.39
Deviance	6818.13	6472.44	8185.78	10153.60	5773.62
Estimated parameters	14	14	14	14	14

Note. Slope and intercept coefficients for each cognitive test are reported in a *t*-score metric; Values in parentheses are standard errors; ISD = intraindividual standard deviation

* $p < .01$

** $p < .001$.

Table 5

HLM Coefficients and Standard Errors for Age Group, Attrition Group, and Complex ISD on Cognitive Tests as a Function of Time to Attrition

	Block Design	Word Recall	Trails A	Trails B	Vocabulary
Fixed Effects					
Intercept					
Returnees	37.00** (0.86)	17.47** (0.31)	37.27** (0.93)	83.75** (2.24)	30.47** (0.38)
Age Group	−1.74 (1.30)	−0.21 (0.50)	5.37* (1.83)	8.46 (4.09)	0.04 (0.56)
Attrition (Personal)	−5.90** (1.55)	−2.73** (0.83)	6.07 (3.51)	22.07* (8.57)	−1.79 (0.84)
Attrition (Family)	−3.81* (1.32)	−1.39* (0.58)	0.84 (1.81)	3.87 (4.52)	−1.03 (0.71)
Complex ISD	−1.38** (0.23)	−0.44** (0.10)	1.47** (0.36)	5.79** (1.07)	−0.28 (0.12)
Slope					
Returnees	0.39 (0.20)	0.05 (0.07)	−0.40 (0.39)	0.20 (0.71)	0.02 (0.03)
Age Group	−0.15 (0.31)	−0.11 (0.11)	−0.85 (0.84)	0.69 (1.19)	−0.01 (0.05)
Attrition (Personal)	−0.60 (0.53)	−0.32 (0.23)	3.68 (2.10)	10.68* (4.07)	−0.34 (0.17)
Attrition (Family)	−0.12 (0.35)	0.11 (0.17)	1.26 (0.61)	1.27 (1.79)	0.08 (0.11)
Complex ISD	−0.09 (0.06)	−0.07** (0.02)	0.22 (0.17)	0.90** (0.27)	−0.02 (0.01)
Random Effects					
Variances					
Level 2, Intercept	66.26**	9.76**	102.25**	499.15**	15.23**
Level 2, Slope	1.34**	0.16**	10.60**	20.81**	0.01*
Level 1, *Residual*	15.27	4.83	65.30	494.18	2.38
Deviance	6801.86	6465.91	8186.63	10148.32	5765.83
Estimated parameters	14	14	14	14	14

Note. Slope and intercept coefficients for each cognitive test are reported in a *t*-score metric; Values in parentheses are standard errors; ISD = intraindividual standard deviation

* $p < .01$

** $p < .001$.

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