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Between-Person and Within-Person Associations among Processing Speed, Attention Switching and Working Memory in Younger and Older Adults

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Abstract

Background/Study Context—Theories of cognitive aging predict associations among processes that transpire within individuals, but are often tested by examining between-person relationships. The authors provide an empirical demonstration of how associations among measures of processing speed, attention switching, and working memory are different when considered between persons versus within persons over time.

Methods—A sample of 108 older adults (M_{age} : 80.8, range: 66–95) and 68 younger adults (M_{age} : 20.2, range: 18–24) completed measures of processing speed, attention switching, and working memory on six occasions over a 14-day period. Multilevel modeling was used to examine processing speed and attention switching performance as predictors of working memory performance simultaneously across days (within-person) and across individuals (between-person).

Results—The findings indicates that simple comparison and response speed predicted working memory better than attention switching between persons, whereas attention switching predicted working memory better than simple comparison and response speed within persons over time. Furthermore, the authors did not observe strong evidence of age differences in these associations either within or between persons.

Conclusion—The findings of the current study suggest that processing speed is important for understanding between-person and age-related differences in working memory, whereas attention switching is more important for understanding within-person variation in working memory. The authors conclude that theories of cognitive aging should be evaluated by analysis of within-person processes, not exclusively age-related individual differences.

Hypothesis testing in psychological aging research involves the analysis of variability in human behavior. Experimental approaches focus on examining age differences in variability produced by manipulations under the researcher's control. In contrast, correlational approaches focus on individual variation resulting from maturation and aging as well as naturally occurring events and processes that are not always identifiable. Researchers in the area of cognitive psychology have historically favored the experimental approach for hypothesis testing. However, the correlational approach has become increasingly influential in evaluating hypotheses regarding the association and disassociation among basic cognitive

processes (e.g. Friedman & Miyake, 2004; Oberauer, Süß, Wilhelm & Wittman, 2003), and hypotheses regarding cognitive age differences (Salthouse, 2001). In fact, analysis of naturally occurring variability is the only means of examining associations among abilities (e.g., working memory, fluid intelligence) that may not be experimentally manipulated.

The central assumption of the correlational approach is that variability and covariability among cognitive performance measures provides information regarding the structure of human cognitive abilities (Davidson & Downing, 2000). However, cognitive performance can be related at two distinct and completely independent levels of analyses: the between-person level and the within-person level. Virtually every correlational study of cognition has relied on the analysis of between-person variability to support theoretical propositions that ultimately seek to explain how cognitive processes operate interdependently within individuals. For example, if one wanted to test the hypothesis that basic processing speed was critical for working memory function, the typical approach would be to measure speed and working memory in a sample of individuals to determine whether fast individuals had higher working memory capacity than slow individuals (e.g., Conway et al., 2002; Salthouse, 2001). The within-person level of analysis addresses this question by using data on processing speed and working memory assessed on multiple occasions and examining whether these two measures travel together over time within individuals. This approach focuses on temporal, and typically short-term, variation in performance.

Because cognitive abilities and processes operate within the minds of individuals, theories of cognition and cognitive aging are inherently within-person. Consequently, the level at which cognitive processes should be associated (i.e., within-persons) and the level at which the covariation among these processes is typically evaluated (i.e., between-persons) have been incongruent. This incongruence is problematic as structure and relations of cognitive functions that operate within individuals is valid only if the structure of variability between-persons is equivalent to the structure of variability within-persons (Molenaar, 2004), and demonstrating the association between two variables (e.g., processing speed and working memory) at the between-person level provides *no* information regarding how these variables are related within-persons (Borsboom et al., 2003; Molenaar, 2004). This argument exposes a significant limitation to the analysis of individual differences in cognition as a means to evaluate claims of how cognitive processes are related within individuals, as well as how these relations may mediate cognitive age differences.

However, few empirical studies have examined within-person relationships among cognitive measures. The few studies that have examined within-person cognitive associations (MacDonald et al., 2003; Sliwinski & Buschke, 2004) have focused on intraindividual variability that largely reflects progressive maturational changes. This research has demonstrated that over long periods (one to several years), there are significant within-person associations between measures of memory and speed which likely reflect coupled age-related changes in these two cognitive domains. However, little is known about the coupling of cognitive function reflected in naturally occurring, short-term performance fluctuations. In order to examine whether two cognitive functions are intrinsically related at the within-person level, one would need to analyze variability over shorter-time intervals to negate the possible influence of long-term developmental trends.

Examining age differences in the magnitude of the within-person coupling may reveal how the structure of cognitive functions varies with age. Only a few studies (Horn, 1972; Hertzog et al., 1992) have examined short-term within-person variability and covariability among cognitive abilities. However, these studies have relied on cognitive measures developed and validated to reliably measure stable traits (e.g., primary mental abilities), and were therefore not designed to be sensitive to short-term performance fluctuations. More generally,

Nesselroade (1991) has remarked that evidence of high behavioral stability may reflect the bias of psychometricians to construct tests that produce temporally stable (e.g., reliable) scores more than they reflect stability in the underlying constructs. Examining basic aspects of information processing might provide more sensitive measures of within-person cognitive variability than tests of global intellectual traits.

The Present Study

Our primary goal was to compare between-person and within-person relationships among working memory, processing speed, and attention switching. Some researchers have argued that variability in working memory reflects variability in basic information processing speed (Jensen, 1992; Salthouse, 1996). Researchers have also postulated that aging-related changes in processing speed drive developmental changes in working memory function (Fry & Hale, 1996; Jensen, 1992; Salthouse, 1991, 1996; Verhaeghen & Salthouse, 1997). If processing speed is indeed fundamental to working memory performance, then we should observe an association of processing speed and working memory within-persons. That is, at times when an individual's processing speed is fast, their working memory performance should be better than at times when their processing speed is slow. Furthermore, in the context of cognitive aging, if processing speed is a central mechanism for understanding age-related variation in working memory performance (e.g., Processing Speed Theory; Salthouse, 1996), then the within-person association between processing speed and working memory should be larger among older adults relative to younger adults.

A complementary prediction comes from research on attention switching and working memory. Working memory is required anytime information must be maintained in memory during active processing, interference, or shifts in attention (Conway et al., 2002). Some researchers have argued that items are held in working memory in one of two states: a state of immediate access (the focus of attention) and an activated portion of long-term memory (e.g., Cowan, 2001). Speed of access distinguishes between these two states, with access speed being much more rapid for items in attentional focus. Accessing items in working memory that are outside the focus of attention therefore incur a cost to retrieval speed, which has been referred to as the attention or focus switch cost (Garavan, 1998; McElree 2001). Verhaeghen (2011; see also Basak & Verhaeghen, 2011; Verhaeghen & Basak, 2005) argued that attention switching is a cognitive primitive that is important for understanding working memory. If attention switching is a basic process involved in working memory performance, then at times when an individual's attention switching is fast, their working memory performance should be better than when their attention switching is slow. Furthermore, Basak and Verhaeghen (2011) hypothesized that attention switching may be important for understanding age-related variation in working memory. If attention switching is a central mechanism for understanding age-related variation in working memory, then the within-person association between attention switching and working memory should be larger among older adults relative to younger adults.

Method

Overview

Participants were given a brief introduction to the study and the experimenter obtained informed consent as approved by the Syracuse University Institutional Review Board. Participants were told that they were participating in a study examining changes in health and cognition in adulthood. Each participant completed six testing sessions over an 8 to 14 day period. The interval between sessions was variable with 70% occurring within 1–2 days of each other, 90% within 4 days, and 99% within 7 days. The maximum interval between sessions was 12 days, which occurred twice and coincided with major observed holidays.

Participants

One hundred-eight older adults ($M = 80.0$, range = 66–95) and 68 younger adults ($M = 20.2$, range = 18–24) were recruited by advertising in local newspapers and by posting flyers in senior centers. The average years of education were similar for young ($M = 15.1$, $SD = 1.4$) and older adults ($M = 14.9$, $SD = 2.4$). The younger and older adult samples had similar proportions of males (.22 vs. .28, respectively). Each participant was compensated \$60.00 for his or her involvement in the study.

Materials

Working Memory—We used a variant of the n -Back task (McElree, 2001; Verhaeghen & Basak, 2005) to assess working memory. This version of the n -Back consisted of displaying a single digit on a computer display and required participants to determine whether the displayed digit matched the n th-digit back (where $n = 1$ or 2) by pressing the “/” key for a match and the “z” key for a non-match. Three blocks of 20 trials were presented for the 1-Back and 2-Back for a total of 60 trials in each condition. The average reaction time across trials for which a correct response was provided on the 2-Back condition served as the dependent variable, while reaction time on the 1-Back was included to covary for the perceptual, decision, and psychomotor demands of the task.

Processing Speed—Processing speed was measured using a computerized number comparison task that required participants to compare two strings of either 3 or 5 digits to determine whether the same digits were in each string, regardless of their order. There were 30 trials of each string length, and the average reaction time across trials for which correct responses were elicited served as the index of processing speed.

Attention Switching—Attention switching was assessed using Garavan’s (1998) event counting procedure that requires keeping a running count of two randomly presented objects. This task consisted of two conditions: a single-count condition that required participants to keep a running count of one type of shape (a circle) and ignore a distractor shape (a diamond) that appeared on 50% of the trials, and a dual-count condition that required subjects to maintain a running count of two different shapes (a triangle and rectangle). Participants were instructed to press the spacebar as soon as they had counted the displayed object, at which time the next object was presented. Both single and dual-count conditions were presented in blocks of trials that consisted of 8, 10, 12, or 16 shapes, with two blocks of each length. Counts were reported at the end of each block, and only response times from blocks with correct counts were included. The average response time across these blocks from the dual-count condition served as index of attention switching.

For all tasks, RTs less than 200 milliseconds or more than 3 standard deviations above the mean for each person were excluded (<1% of possible RTs were excluded). Previous analyses of these data (Sliwinski et al., 2006) indicate good reliability of between-person variability (Single-Count: .84–.91; Dual-Count: .83–.92; Processing Speed: .92–.94; 1-Back: .86–.91; 2-Back: .81–.88) and day-to-day within-person variability (Single-Count: .70–.78; Dual-Count: .73–.74; Processing Speed: .65–.78; 1-Back: .65–.73; 2-Back: .69–.73).

Procedure

The order of administration of cognitive tasks was fixed across sessions and individuals: attention switching (single- then dual-count), processing speed (3- then 5-digit), and working memory (1- then 2-back). A high-resolution monitor controlled by a Pentium IV-based computer displayed stimuli. During the first session, sufficient practice trials for all tasks were provided until participants become comfortable with each procedure.

Approximately 10 warm-up trials were given prior to commencing each task during sessions 2–6. For further information on the procedure and tasks, see Sliwinski et al. (2006).

Statistical Analysis

Multilevel models were used to model working memory performance, and to simultaneously examine between- and within-person predictors of working memory performance using SAS PROC MIXED. Practice related decreases in RT common to all tasks were modeled using a 2nd order polynomial model in a linear multilevel model (Raudenbush & Bryk, 2002; see Sliwinski et al., 2006 for a detailed treatment of different mathematical approaches for modeling practice-related time trends using this data).

$$\text{Level 1: } 2\text{-backRT}_{ij} = b_{0j} + b_{1j}(\text{session}_{ij}) + b_{2j}(\text{session}_{ij}^2) + e_{ij} \quad (1a)$$

Equation 1a states that, at level 1, the average 2-back RT for person j during session i is a function of an intercept (b_{0j}), linear (b_{1j}) and quadratic (b_{2j}) session trends, and a residual (e_{ij}). The model was centered at the first session such that the intercept reflects the sample average response time at the first session, the linear slope reflects the instantaneous rate of change in response time at the first session, and the quadratic slope reflects deceleration in the rate of change in response times across sessions. The level 2 model (Equation 1b) states that a_{00} , a_{10} , and a_{20} are the average within-person intercept, linear, and quadratic trends, or fixed effects, while u_{0j} , u_{1j} , and u_{2j} are individual deviations from the average values, or random effects.

$$\begin{aligned} \text{Level 2: } b_{0j} &= a_{00} + u_{0j} \\ b_{1j} &= a_{10} + u_{1j} \\ b_{2j} &= a_{20} + u_{2j} \end{aligned} \quad (1b)$$

For Model 1b, all of the random effects (u_{0j} , u_{1j} , and u_{2j}) were estimated separately for younger and older adults. Similarly, separate residuals (e_{ij}) were estimated for each age group. All random effects and covariances among random effects were freely estimated using an unstructured variance/covariance matrix, and the residuals were assumed to be constant across sessions.

Processing speed and attention switching were included as both between- and within-person predictors of working memory involving a simple extension of Models 1a and 1b. The between-person effect was obtained by taking each individual's average processing speed (or attention switching) from across the six sessions ($\overline{\text{speed}_{.j}}$). The within-person estimate was obtained via person-centering, reflecting daily deviations from one's own average processing speed ($\text{speed}_{ij} - \overline{\text{speed}_{.j}}$), and reflects exclusively within-person variability.

$$\text{Level 1: } 2\text{-backRT}_{ij} = b_{0j} + b_{1j}(\text{session}_{ij}) + b_{2j}(\text{session}_{ij}^2) + b_{3j}(\text{speed}_{ij} - \overline{\text{speed}_{.j}}) + e_{ij} \quad (2a)$$

$$\begin{aligned} \text{Level 2: } b_{0j} &= a_{00} + a_{01}(\text{Age}_{.j}) + a_{02}(\overline{\text{speed}_{.j}}) + a_{03}(\text{Age}_{.j} \times \overline{\text{speed}_{.j}}) + u_{0j} \\ b_{1j} &= a_{10} + a_{11}(\text{Age}_{.j}) + u_{1j} \\ b_{2j} &= a_{20} + a_{21}(\text{Age}_{.j}) + u_{2j} \\ b_{3j} &= a_{30} + a_{31}(\text{Age}_{.j}) \end{aligned} \quad (2b)$$

Equation 2a states that in addition to the linear and quadratic session trends, working memory on day i for individual j is also a function of that individual's processing speed on that day (b_{3j}). The inclusion of between-person effects for processing speed and age are shown in Equation 2b. The between-person effect of processing speed (a_{02}) was included at level 2 and tests for covariation among individual differences in processing speed and working memory. Age group, a dichotomous variable, was also added at level 2, and parameters a_{01} , a_{11} , a_{21} , and a_{31} test for age group differences in level of working memory, linear and quadratic practice trends, and the within-person coupling of processing speed and working memory, respectively. Parameter a_{03} is an interaction term testing for an age difference in the between-person association between processing speed and working memory. An identical model was used to test the effects of attention switching by replacing the processing speed variables with the attention switching variables.

Statistical Models for Testing Primary Hypotheses

For examining processing speed and attention switching as predictors of working memory performance both between-persons as well as within-persons across session, we estimated two models. The first model included the between- and within-person effects of processing speed (or attention switching) and interactions with age group predictors of working memory, providing a direct test of associations between processing speed (and attention switching) both between- and within-persons. The second model was a simple extension of the first, simply including performance on the 1-back version working memory task as a covariate. The 1-Back task places the same demands on perceptual, decision and psychomotor speed as does the 2-Back, but does not require individuals to shift attentional focus from trial-to-trial (McElree, 2001; Verhaeghen & Basak, 2005). As such, this allowed us to covary for the perceptual, decision and psychomotor speed characteristics specific to the n-back task, and consider whether processing speed and attention switching predictive of working memory, ruling out these task-specific characteristics as potential confounds.

Results

Variance Decomposition of Working Memory, Processing Speed, and Attention Switching

Table 1 displays the estimates of between-person and within-person variation and intraclass correlation coefficients (ICCs) for the working memory, processing speed, and attention switching tasks, obtained from unconditional (empty) multilevel models. Across all tasks, all estimates were significant indicating heterogeneity in task performance across persons, as well as within-persons across session. The ICCs, which provide an index of the proportion of total variation reflecting between-person differences, ranged from .81 to .92. Thus, between 81% and 92% of the variation in performance on the tasks reflects differences between-persons, with the remaining 8% to 19% reflecting variations in tasks performance within-persons over time.

Age Differences in Working Memory

Table 2 displays the results of the analysis of practice effects and age differences in working memory. Older adults exhibited markedly slower working memory performance at the first session compared to younger adults (2249ms vs. 1547ms; estimate = -699.54 , SE = 107.35). Furthermore, there was evidence of significant practice effects for both younger and older adults, as indicated by the significant linear and quadratic session effects. The linear session fixed effects indicated that instantaneous rate of change in response times (RTs) on the working memory task, at the first session, was significant and negative for both younger (estimate = -302.80 , SE = 19.59) and older adults (estimate = -179.44 , SE = 40.17). The quadratic session fixed effect was significant and positive for younger (estimate = 27.85, SE = 2.78) and older adults (estimate = 14.68, SE = 5.17) indicating that while performance on

the working memory task was getting faster across sessions, this rate of improvement decelerated over time.

Processing Speed Predicting Working Memory

Model 1 in Table 2 shows the results from the analysis of the within- and between-person associations between processing speed and working memory (2-back). The within-person associations indicated that the 2-back performance of the younger adults was slower on days when their processing speed was slower as well (estimate = .11, SE = .05), whereas no such association was observed among the older adults (estimate = .04, SE = .06). Furthermore, the two groups did not significantly differ in the magnitude of the within-person association between processing speed and working memory (estimate = .07, SE = .08). The between-person associations indicated that for younger adults, individuals who exhibit slower than average processing speed also exhibit slower than average 2-back performance (estimate = .21, SE = .08). The same association emerged for the older adults (estimate = .33, SE = .08), however, the magnitude of the association did not differ between the groups (estimate = -.12, SE = .12). Additionally, the age difference in working memory was no longer significant (estimate = -159.57, SE = 280.22) after controlling for processing speed.

Model 2 in Table 2 shows that the within-person associations between 1-Back and 2-Back performance were significant for younger (estimate = .33, SE = .15) and older (estimate = .38, SE = .08) adults. Similarly, the between-person associations between 1-Back and 2-Back performance were significant for both younger (estimate = 1.01, SE = .45) and older (estimate = 1.39, SE = .17). Importantly, controlling for 1-Back performance rendered the within-person association between processing speed and 2-Back performance for the younger adults (estimate = .09, SE = .05) no longer statistically significant. Controlling for 1-Back performance also reduced the between-person associations between processing speed and 2-Back performance to a non-significant level for both younger (estimate = .14, SE = .09) and older (estimate = -.02, SE = .08) adults. These results imply that both the within-person and between-person relationship between processing speed and 2-Back reflected variance shared with 1-Back performance.

Attention Switching Predicting Working Memory

Model 1 in Table 3 shows the results from the analysis of the within- and between-person associations between attention switching (dual-count condition) and working memory (2-back). The within-person association between attention switching and 2-back performance was significant for both younger (estimate = .23, SE = .10) and older (estimate = .26, SE = .10) adults, indicating that both younger and older adults working memory performance was slower on days when their attention switching performance was slower. The magnitude of this effect, however, was not significantly different between the two groups (estimate = -.03, SE = .14). The between-person association was significant for both younger (estimate = .32, SE = .14) and older (estimate = 1.07, SE = .23) adults, however the effect was significantly smaller among younger adults (estimate = -.75, SE = .27). Therefore, individuals who exhibit slower than average attention switching performance also exhibit slower working memory, and this effect is accentuated among older adults compared to their younger counterparts. Furthermore, controlling for attention switching attenuated the age difference in working memory (estimate = 211.07, SE = 297.58,)

Once again, we estimated a second model controlling for 1-Back performance, the results of which can be seen in Table 3 (Model 2). Controlling for 1-Back performance had little effect on the within-person association between attention switching and 2-Back performance as the effect was remained significant for both younger (estimate = .19, SE = .09) and older (estimate = .24, SE = .10) adults. The between-person associations, however, were no longer

significant for either younger (estimate = .12, SE = .16) or older (estimate = .28, SE = .20). These results indicate that between-person association between attention switching and 2-Back performance is attributable to variance shared with 1-Back performance, but that within-persons, attention switching is uniquely predictive of 2-Back performance for both younger and older adults.

Finally, we used cross-sectional age differences in working memory performance as an index for gauging the magnitude of the within-person associations among of processing speed, attention switching and working memory (e.g., Sliwinski et al., 2006). Here, we estimated a 1-year age difference in processing speed (or attention switching) two ways. First, we took the difference between the average response times for young and older adults, and divided this difference by 60, the difference between the mean ages of the two groups, quantifying a 1-year age difference in processing speed (or attention switching) assuming a linear association across the adult lifespan. Second, we obtained the estimate of a 1-year age difference in performance among the older adults. Standardized within-person processing speed and attention switching effects were calculated by multiplying the within-person effects reported in Tables 2 and 3, by the appropriate within-person standard deviation, and multiplied that value by 2. This reflects the total difference between a day when individuals' processing speed and attention switching are slower than average and when they are faster than average. These results are shown in Figures 1a and 1b.

The right two bars in figure 1a indicate that the difference between days when individuals' processing speed is slower than usual and when it is faster than usual is approximately 23ms for the younger adults and 16ms for the older adults. Thus, the within-person coupling of processing speed and 2-back performance, for young and old adults, is roughly equivalent to a 1-year age difference in processing speed. The right two bars in figure 1b show that the difference between days when individuals attention switching is slower than usual and when it is faster than usual is 29ms for the young adults and 62ms for the old adults. Thus, the magnitude of the within-person coupling of attention switching and 2-back performance is 5.5 times greater than the observed cross-sectional age differences for young adults and 12 times greater for the older adults.

Supplemental Analyses

We explored two additional models examining processing speed as a covariate when examining the associations between attention switching and working memory performance. The first model used processing speed in lieu of the 1-back task, and the second model included processing speed in addition to the 1-back task. The direction of effects and pattern of significance remained the same regardless of our inclusion of processing speed as a covariate, and processing speed was not a significant predictor of working memory independent of attention switching or 1-back performance. Finally, given the well-known non-normality of RT distributions, we re-estimated all models using log-transformed RTs and found the pattern of results and significant effects remained the same.

Discussion

The general goal of this study was to demonstrate the feasibility and utility of supplementing conventional analyses of individual differences in cognition with complementary analyses of intraindividual variability in cognition. Although research has demonstrated systematic individual differences in the magnitude of intraindividual cognitive variability, this study is unique in demonstrating systematic day-to-day fluctuations in basic aspects of information processing by showing that performance on cognitive measures are coupled within-individuals. We accomplished this goal by contrasting the within-person and between-

person relationships of processing speed and attention switching with working memory, and by examining age differences in the pattern of these relationships.

The within-person relationship between attention switching and working memory was much more specific and robust than the corresponding between-person relationship. Within-person variability in dual-count performance remained a significant predictor of daily fluctuations in 2-Back performance after controlling for practice gains, stimulus encoding and response speed, indicating that this relationship was not reflective of a generalized effect (e.g., fatigue, motivation) of within-person fluctuations in speeded performance. Moreover, we demonstrated that this relationship was specific to processing demands present in the dual-but not single-count condition. A critical difference between dual-count and single-count performance is that only the former requires repeated shifts of attentional focus from one running count to the other (Garavan, 1998). These results support the contention of Verhaeghen and colleagues (Verhaeghen & Basak, 2005), that attention or focus switching is a critical working memory control process.

The between-person association between attention switching and working memory, however, was no longer statistically significant after controlling for stimulus encoding and response speed. The discrepancy between the within- and between-person associations indicates that the results obtained from the two levels of analysis were nonergodic: findings from analysis of within-person variability and between-person variability did not converge on similar results. Specifically, the between-person association between dual-count and 2-Back performance largely reflected individual differences in processing demands that were also present in the simple 1-Back condition (i.e., comparison speed, response execution speed) that did not require attention switching. This suggests that the between-person relationship reflected general task demands related to speeded performance, whereas the within-person relationship reflected task demands specific to the 2-Back and dual-count conditions. Thus, the within-person analyses revealed a different level of process specificity than did the corresponding between-person analysis.

Similar results were observed with respect to processing speed as within-person fluctuations in processing speed did not strongly predict fluctuations in working memory, especially after controlling for the processing demands via 1-Back performance. These findings raise the question of why processing speed is a more important predictor of between-person variability than within-person variability. One explanation is that individual differences in processing speed may provide a very general index of brain integrity and health (Christensen, et al., 2001), rather than a specific marker of information processing that is common to many different cognitive tasks. Individual differences in processing speed may reflect cumulative developmental differences in global health and brain function that can differentiate between people on other measures of cognitive function. Although measures of simple processing speed may provide a good general assay of how efficiently the brain processes information, that would not imply that processing speed provides an index of specific information processing operations that are fundamental to individual differences in working memory (or any other specific type of cognitive function). Indeed, our failure to observe significant associations among processing speed and working memory within-persons casts doubt regarding theoretical accounts which posit that processing speed is the central mechanism implicated in working memory (Jensen, 1992; Salthouse, 1996).

In cognitive aging literature, processing speed has been proposed as a central mechanism for understanding age-related variation in working memory (Salthouse, 1996; Verhaeghen & Salthouse, 1997). Our inclusion of processing speed at the between-person level did attenuate the observed age differences in working memory (see Table 3, Model 1), consistent with the predictions of Processing Speed Theory (Salthouse, 1996). However, the

lack of within-person coupling between older adults processing speed and n -back performance, or this association increasing in strength with age, does not support the contention that processing speed is an important determinant of daily variation in working memory in old age (Jensen, 1992; Salthouse, 1991; 1996; Verhaeghen & Salthouse, 1997). However, controlling for the perceptual, decision, and psychomotor demands of the n -back task rendered any observed effects of processing speed non-significant, suggesting that the role of processing speed for explaining age-related differences in working memory should be viewed with appropriate circumspection.

With respect to attention switching as a mechanism for explaining age-related differences in working memory (Basak & Verhaeghen, 2011; Verhaeghen & Basak, 2005; Verhaeghen, 2011), the current study provided limited support. While the observed age difference in working memory was attenuated after the inclusion of attention switching at the between-person level (see Table 4, Model 1), the between-person effect of attention switching was not significant after covarying for the perceptual, decision, and psychomotor demands of the n -back task. While within-person fluctuations in attention switching were significantly associated with working memory performance, the magnitude of this association did not differ between the younger and older adults. The lack of age-related increase in the within-person association does not provide strong support for attention switching holding increased importance for understanding working memory in advanced age. However, the lack of an age difference in this within-person association does provide support for arguments made by Verhaeghen and Basak that attention switching appears to be a cognitive primitive that is an important mechanism for understanding working memory in general. Taken together with the between-person findings examining processing speed and working memory, the data from the current study certainly seem to lend more support to some dimension of response/perceptual speed (e.g. Salthouse, 1996), as opposed to attention switching as a candidate for age-related differences in working memory across individuals. In contrast, the within-person findings regarding associations among processing speed, attention switching, and working memory suggest that attention switching, but not processing speed, is important for understanding fluctuations in working memory regardless of age.

An important next step in the study of within-person cognitive variability would be to model the coupling of different cognitive processes at the latent construct level, as well as across different time intervals. The difficulty in pursuing this line of research resides in the fact that familiar constructs that have been demonstrated and validated by studies of individual differences might not be present within individuals (e.g., Molenaar, 2004). For example, constructs such as intelligence, working memory capacity, and short-term memory capacity have a rich history of use when considering individual differences in cognitive function (e.g., Conway et al., 2002), but may be less susceptible to fluctuations and changes over time. Other aspects of cognitive function, such as selective attention, inhibition, attentional control and lapses of attention, may be more likely to exhibit systematic fluctuations, and may be better suited for understanding how cognitive functions are coupled within-individuals over time.

The results of the current study have shown the feasibility of detecting and explaining intraindividual variability in day-to-day cognitive performance in younger and older adults, and that the magnitude of within-person associations can be considerable. Furthermore, the lack of concordance at the between- and within-person levels of analysis demonstrates the charges put forth by Molenaar (2004) and Borsboom et al. (2003) who urge caution about relying upon between-person associations for making inferences about within-person processes. The current results underscore the importance of considering the level of analysis for answering questions about relationships among cognitive processes and how these relationships vary with age.

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1A

1B

Figure 1. Cross-sectional age differences and standardized within-person (WP) coupling effects on 2-back performance for (A) Processing Speed, and (B) Attention Switching.

Table 1

Variance Estimates and Intraclass Correlation Coefficients for Processing Speed, Attention Switching and Working Memory Tasks.

	Processing Speed	Attention Switching	Working Memory
Between-Person Variance	661927**	71779**	488985**
Within-Person Variance	56440**	16586**	94505**
ICC	.92	.84	.81

Note:

*
 $p < .05$,

**
 $p < .01$.

Table 2

Multilevel Model Estimates of Age Differences and Practice Trends in Working Memory.

	Young	Old	Difference
Fixed Effects	Estimate (SE)	Estimate (SE)	Estimate (SE)
Intercept	1547.22 (50.67) **	2246.76 (94.94) **	-699.54 (107.35) **
Session	-302.80 (19.59) **	-179.44 (40.42) **	-123.36 (44.91) **
Session ²	27.85 (2.48) **	14.68 (5.17) **	13.17 (5.73) *
Random Effects	Estimate	Estimate	
Var(Intercept)	143082 **	756124 **	
Var(Session)	14672 **	87334 **	
Var(Session ²)	196.83 **	1158.26 **	
Cov(Intercept. Session)	-34344 **	-176785 **	
Corr(Intercept. Session)	-.75	-.70	
Cov(Intercept. Session ²)	2842.80 **	21019 **	
Corr(Intercept. Session ²)	.54	.71	
Cov(Session. Session ²)	-1533.12 **	-9873.85 **	
Corr(Session. Session ²)	-.90	-.98	
Residual	7387.46 **	61271 **	

Note:

*
p<.05,**
p<.01.

Cov: Covariance, Corr: Correlation

Table 3

Multilevel Model Parameter Estimates of Processing Speed Predicting 2-Back Performance.

Fixed Effects	Model 1	Model 2
	Estimate (SE)	Estimate (SE)
Intercept		
Young	1190.02 (138.44) **	693.73 (238.81) **
Old	1349.60 (243.63) **	744.73 (207.98) **
Difference	-159.57 (280.22)	-.50.99 (316.68)
Processing Speed (WP)		
Young	.11 (.05) *	.09 (.05)
Old	.04 (.06)	.04 (.06)
Difference	.07 (.08)	.05 (.08)
Processing Speed (BP)		
Young	.21 (.08) **	.14 (.09)
Old	.33 (.08) **	-.02 (.08)
Difference	-.12 (.12)	.16 (.12)
1-Back (WP)		
Young	-	.33 (.15) *
Old	-	.38 (.08) **
Difference	-	-.04 (.17)
1-Back (BP)		
Young	-	1.01 (.45) *
Old	-	1.39 (.17) **
Difference	-	-.38 (.48)

Note:

⁺
 $p < .10$,^{*}
 $p < .05$,^{**}
 $p < .01$.

WP: Within-Person, BP: Between-Person.

Table 4

Multilevel Model Parameter Estimates of Attention Switching Predicting 2-Back Performance.

Fixed Effects	Model 1	Model 2
	Estimate (SE)	Estimate (SE)
Intercept		
Young	1026.89 (270.85) **	410.04 (223.43) ⁺
Old	1237.96 (123.25) **	744.82 (226.29) **
Difference	211.07 (297.58)	334.78 (318.01)
Dual Count (WP)		
Young	.23 (.10) *	.19 (.09) *
Old	.26 (.10) **	.24 (.10) *
Difference	-.03 (.14)	-.05 (.14)
Dual Count (BP)		
Young	.32 (.14) *	.12 (.16)
Old	1.07 (.23) **	.28 (.20)
Difference	-.75 (.27) **	-.16 (.26)
1-Back (WP)		
Young	-	.33 (.13) *
Old	-	.33 (.08) **
Difference	-	-.00 (.15)
1-Back (BP)		
Young	-	1.09 (.48) *
Old	-	1.34 (.16) **
Difference	-	-.25 (.51)

Note:

⁺
 $p < .10$,*
 $p < .05$,**
 $p < .01$.

WP: Within-Person, BP: Between-Person.