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Performance inconsistency and cognition following stroke in older adults

by

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Abstract

As a measure of neurological integrity, inconsistency was examined in stroke and healthy control participants from the Victoria Longitudinal Study in three studies. Study 1 compared $n = 23$ stroke and $n = 23$ control participants on inconsistency and revealed that stroke participants had greater variability on a choice reaction time task compared to controls. In Study 2, $n = 10$ right-hemisphere damaged and $n = 4$ left-hemisphere damaged participants were compared in inconsistency. The groups did not differ in level of inconsistency. Study 3 compared $n = 17$ mild stroke, $n = 5$ moderate stroke, and $n = 22$ controls on inconsistency. At Occasion 1, moderate stroke participants showed greater inconsistency compared to both mild and control groups, which did not differ from each other. Overall, greater variability is related to poorer cognitive functioning, and greater variability on one task is associated with greater variability on another task.

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Following heart disease and cancer, cerebrovascular accidents rank third among the leading causes of death in North America (Adams & Ropper, 2001; Babikian, Kase, & Wolf, 1994). Strokes can be characterized by their location, size, temporal sequence, and mechanism. Each of these factors directly affect the type and severity of the neurological damage and, in turn, have implications for the resulting cognitive impairments (Hom & Reitan, 1990). In addition to the global cognitive deficits that have been observed following a stroke (e.g., Bowler, Hadar, & Wade, 1994; Hochstenbach, Mulder, van Limbeek, Donders, & Schoonderwaldt, 1998; Tatemichi, Desmond, Stern, Paik, Sano, & Bagiella, 1994), impairments in specific cognitive domains have also been found. For instance, stroke-related impairments in memory (Beeson, Bayles, Rubens, & Kaszniak, 1993; Bowler et al., 1994; Stewart, Sunderland, & Sluman, 1996; Tatemichi et al., 1994), attention (Korda & Douglas, 1997), speed of information processing (Hochstenbach et al., 1998; Leskelä et al., 1999), executive functioning (Leskelä et al., 1999), visuospatial performance (Moya, Benowitz, Levine, & Finklestein, 1986), fine-motor speed (Haaland & Harrington, 1994) and language comprehension (Hough, 1990; Titone, Wingfield, Caplan, Waters, & Prentice, 2001) have been documented.

Investigating the effect of stroke on cognitive functioning in older adults is important for the following interrelated reasons. First, not only is the number of individuals surviving into old age dramatically increasing (Bäckman, Small, Wahlin, & Larsson, 2000; Wahlin, 2004), but the incidence of stroke steadily increases with advancing age (Babikian et al., 1994; Walker, Robins, & Weinfeld, 1981, as cited in Bäckman et al., 2000). Second, although stroke is the third leading cause of death, it is actually more often disabling than lethal. In fact, cerebrovascular incidents are the

leading cause of cognitive (e.g., memory) and other impairments among the elderly (Walker et al., 1981, as cited in Bäckman et al., 2000). Third, although much recent progress has been made in understanding the neuropsychological and health underpinnings of cognitive aging, little is known about the cognitive sequelae of mild stroke (Dixon, Bäckman, & Nilsson, 2004). In sum, more older adults than ever before are living longer with cognitive deficits following a stroke. This highlights the importance and practicality of learning more about the indicators and consequences of such common cerebrovascular incidents.

Like most cognitive and neuropsychological research, cognitive aging research has primarily focused on indicators of performance aggregated at the group level. Thus, cross-sectional group differences (e.g., younger vs. older adults) are evaluated at the level of single-occasion group means, whereas longitudinal change is evaluated using multi-occasion differences in mean performance. Recently, it has become increasingly clear that performance indicators of variability may reflect important phenomena in cognitive and neuropsychological research. Accordingly, several studies of within-person variability in cognitive performance over short intervals (i.e., trials, days, weeks) have been conducted. Nesselroade (1991) distinguished between two types of within-person variability: *intraindividual change*, which refers to relatively slow and enduring change (e.g., learning, development), and *intraindividual variability*, which refers to relatively short-term, rapid and transient change (e.g., mood states, fluctuations in performance). In the cognitive aging literature, the latter term has been referred to as *inconsistency* (Hultsch & MacDonald, 2004; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000).

Intraindividual variability in cognitive performance can be reliably measured, even after accounting for systematic effects associated with practice, materials, or other influences (Anstey, 1999; Hultsch et al., 2000; Li, Aggen, Nesselroade, & Baltes, 2001; Martin & Hofer, 2004). For example, Hertzog, Dixon, and Hultsch (1992) examined story recall performance in a group of seven older women tested on a weekly basis for up to two years (maximum of 90 occasions). They found considerable intraindividual variability in story recall across occasions, despite having accounted for practice effects, materials effects, and other systematic changes over time. Research with healthy older adults has consistently revealed that intraindividual variability in cognitive performance (e.g., reaction time, text recall) increases with age (Anstey, 1999; Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994; Hultsch, MacDonald, & Dixon, 2002; Shammi, Bosman, & Stuss, 1998). For example, Hultsch et al. (2002) compared younger adults and three groups of older adults (i.e., young-old, mid-old, and old-old) on their trial-to-trial performance on four reaction time (RT) tasks. Older adults, especially those over age 75, exhibited increased intraindividual variability relative to younger adults on all tasks. Notably, these significant age differences were observed even after statistically controlling for both between-group differences in speed and practice or learning-to-learn effects. Age-related differences in inconsistency have also been found across longer time intervals. In a study by Li and colleagues (2001) intraindividual variability on a set of memory and sensorimotor measures was examined in older adults across 13 bi-weekly sessions. A positive correlation was found between intraindividual variability and age for most sensorimotor measures and one of the memory measures.

Intraindividual variability has also been found to be a relatively stable characteristic in individuals. Specifically, recent analyses have demonstrated that individuals who show more inconsistency across trials within a session also tend to show more inconsistency across testing sessions separated by longer time intervals (e.g., weeks) (Fuentes, Hunter, Strauss, & Hultsch, 2001; Hultsch et al., 2000; Rabbitt, Osman, Moore, & Stollery, 2001; West, Murphy, Armilio, Craik, & Stuss, 2003). Moreover, it has been found that individuals who show more inconsistency on one task also tend to show more inconsistency on other tasks (Burton, Hultsch, Strauss, & Hunter, 2002; Fuentes et al., 2001; Hultsch et al., 2000). Finally, positive relationships have been found between different measures of within-person variability. For example, Hultsch and colleagues (2002) have shown that individuals with greater intraindividual variability in performance across four RT tasks also exhibited greater dispersion, or variability in profiles of performance across the four RT tasks. Similarly, a number of studies have demonstrated that cross-domain linkages exist among measures of variability (Burton et al., 2002; Li et al., 2001; Strauss, MacDonald, Hunter, Moll, & Hultsch, 2002). For example, Strauss et al. (2002) observed positive correlations between measures of intraindividual variability on physical and cognitive tasks. They found that individuals who demonstrated greater variability in one domain also demonstrated greater variability in the other domain. Taken together, these results indicate that inconsistency is stable across time intervals as well as tasks.

Not only has inconsistency been found to be a stable characteristic in individuals, but greater inconsistency has been found to be associated with lower levels of both general intelligence (Rabbitt et al., 2001) and cognitive performance (Hultsch et al.,

2000, 2002; Li et al., 2001; Nesselroade & Salthouse, 2004). In one study, Rabbitt and colleagues (2001) measured older adults' inconsistency in reaction time on a letter identification task both within and across sessions. Greater inconsistency was associated with lower intelligence, as indexed by the Culture Fair Intelligence Test, both within trials of a session and also across weekly testing sessions. Similarly, Hultsch et al. (2002) observed an association between greater inconsistency in RT and poorer level of performance on measures of perceptual speed, working memory, episodic memory, and crystallized intelligence. Notably, this study also revealed that measures of inconsistency and level of performance are unique predictors of cognitive performance. Several other recent studies have confirmed this finding (e.g., Fuentes et al., 2001; Li et al., 2001; Hultsch et al., 2000; Rabbitt, 2000), highlighting the importance of considering both measures of inconsistency and level of performance in cognitive aging research.

The relative consistency of individual differences in measures of intraindividual variability across time intervals and tasks suggests that the magnitude of intraindividual variability is a measurable characteristic of the individual. Despite this, it is not entirely clear what might cause or control intraindividual variability in individuals. Intraindividual variability may reflect (a) relatively stable endogenous influences (e.g., neurological mechanisms), (b) relatively stable exogenous influences, (c) relatively labile endogenous influences, or (d) relatively labile exogenous influences (e.g., pain, fatigue, stress). Some researchers believe that endogenous (and especially neurological) mechanisms may be involved in accounting for age differences in intraindividual variability in performance. Indeed, several researchers have theorized that performance inconsistency at the behavioural level may be an indicator of central nervous system

(CNS) functioning. More specifically, Hendrickson (1982) and Li and Lindenberger (1999) have suggested that intraindividual variability in performance could be the result of random errors or neural "noise" in the transmission of neural signals in the CNS. For example, Li and Lindenberger (1999) have recently proposed that catecholaminergic neurotransmitters, such as dopamine, may regulate the signal-to-noise ratio of neural information processing. Through the use of computational modeling, these researchers simulated reduced dopamine regulation of the signal-to-noise ratio and observed increased intranetwork variability in the aging brain.

Evidence in support of the CNS-neural-noise hypothesis comes from an accumulating body of research on individuals with compromised neurological functioning. Specifically, empirical studies have demonstrated that inconsistency in performance is prevalent in individuals with various types of neurological dysfunction including epilepsy (Bruhn & Parsons, 1977), mental retardation (Wade, Newell, & Wallace, 1978), traumatic brain injury (TBI; Bleiberg, Garmoe, Halpern, Reeves, & Nadler, 1997; Burton et al., 2002; Hetherington, Stuss, & Finlayson, 1996; Stuss et al., 1989; Stuss et al., 1994), chronic fatigue syndrome (Fuentes et al., 2001), and dementia (Gordon & Carson, 1990; Hultsch et al., 2000; Knotek, Bayles, & Kaszniak, 1990). For example, Hultsch et al. (2000) compared healthy, arthritic, and mildly demented older adults on their inconsistency on RT and episodic memory tasks. Patients diagnosed with mild dementia showed greater intraindividual variability in performance relative to the other two groups of neurologically intact older adults. These findings suggest that intraindividual variability may be a consequence of neurological disturbance rather than somatic conditions (e.g., pain). Consistent with such findings, recent research has shown

that older adults in a pre-clinical phase of dementia (i.e., individuals diagnosed as having a mild cognitive impairment) exhibit greater inconsistency in cognitive performance relative to healthy older adults (Christensen, Dear, Anstey, Parslow, Sachdev, & Jorm, in press). Intraindividual variability in cognitive performance has the potential to be a good marker of neurological diseases in the pre-clinical phase, such as Alzheimer's disease (Li & Lindenberger, 1999) and dementia (Christensen et al., in press).

Interestingly, not only has research with clinical populations revealed greater inconsistency in performance, but also that such inconsistency may differentiate between different forms of brain damage. For example, Murtha, Cismaru, Waechter, and Chertkow (2002) found that frontal lobe dementia patients exhibited greater inconsistency in performance compared to individuals diagnosed with dementia of the Alzheimer's type. Similarly, other work has found intraindividual variability to be associated with the frequency of seizures in epileptic patients (Bruhn & Parsons, 1977). Not all studies, however, have found measures of intraindividual fluctuations to be particularly useful in predicting neurological status. Specifically, inconsistency did not distinguish between levels of severity in TBI patients (e.g., Burton et al., 2002; Stuss et al., 1994), between sub-groups with mild cognitive impairment (Christensen et al., in press), or even between patients with various forms of dementia (Taylor, Gilleard, & McGuire, 1991). For instance, Taylor et al. (1991) examined inconsistency in cognitive performance across three bi-weekly sessions, comparing older patients with multi-infarct dementia and patients with dementia of the Alzheimer type. These researchers found no difference in inconsistency between the two groups. However, measures of inconsistency

were taken only over three bi-weekly sessions; perhaps some differences in inconsistency may have emerged if there were more occasions of measurement.

Despite the growing interest in examining intraindividual variability in both healthy and neurologically-impaired individuals, only one other study to date has investigated performance variability in stroke patients. In this study, stroke patients diagnosed with cognitive impairment no dementia (CIND) exhibited greater variability on a choice reaction time task relative to stroke patients who were not diagnosed with CIND (Ballard, Stephens, Kenny, Kalaria, Tovee, & O'Brien, 2003). Because no healthy control group was included in this study, it is not clear whether cognitive impairment, as opposed to stroke per se, resulted in inconsistency, or whether the combined effects of stroke and cognitive impairment resulted in inconsistency. Examining intraindividual variability in stroke patients may be an important and fruitful area of research for the following reasons. First, it has been shown that individuals who have had a mild stroke have subtle but disruptive deficits in some cognitive domains (Mansueti, de Frias, Dixon, & Bub, in preparation), which may even go undetected. Such deficits have only been examined at the mean level of performance. Thus, by examining intraindividual variability in addition to mean level of performance, we may be able to tap into even more subtle deficits in mild stroke patients. Second, measuring intraindividual variability can be useful in trying to understand the recovery process following a mild stroke. For instance, research with TBI patients has demonstrated that individuals with a shorter time since injury have greater inconsistency compared to those with a longer time since injury (Hetherington et al., 1996; Stuss et al., 1989). These results suggest that inconsistency may be sensitive to the recovery of function in individuals with neurological damage.

Related to this issue is the argument that because performance is highly variable, one occasion of measurement may not provide an accurate picture of an individual's cognitive functioning (Dixon et al., 1993; Kliegel & Sliwinski, 2004). Furthermore, others have claimed that intraindividual variability may be particularly significant in assessing individuals whose disorders are mild or not easily definable (Gordon & Carson, 1990; Hultsch et al., 2000; Stuss et al., 1994). Finally, examining inconsistency in stroke patients may have clinical benefits in terms of detecting vascular dementia after a stroke. Some preliminary findings in support of this idea comes from the study by Ballard et al. (2003) in which it was found that stroke patients with a diagnosis of CIND showed more variability on a choice reaction time task compared to stroke patients who were not diagnosed as having CIND.

The purpose of the present thesis is to examine intraindividual variability in older adults who have had a mild stroke. Three studies are described. The goals of Study 1 are: (a) to examine whether mild stroke participants show more inconsistency on RT tasks compared to healthy controls, and (b) to explore whether inconsistency is related to performance on other cognitive tasks differentially for the stroke and control groups. Given that some preliminary findings suggest that intraindividual variability may be useful in differentiating between different forms of brain damage, the purpose of Study 2 is to explore whether inconsistency varies as a function of lesion laterality. Specifically, the goals of Study 2 include: (a) to explore whether right-hemisphere damaged (RHD) and left-hemisphere damaged (LHD) participants' intraindividual fluctuations differ, and (b) to examine whether inconsistency is related to cognitive tasks differentially for these two groups. Although some preliminary findings reveal that intraindividual fluctuations

do not distinguish between levels of severity in TBI patients, for example, no other studies to date have examined whether inconsistency can distinguish between levels of severity in stroke patients. Accordingly, the goals of Study 3 are: (a) to explore whether mild, moderate, and healthy controls differ in their levels of inconsistency, (b) to examine whether inconsistency is related to performance on cognitive tasks differentially for these groups, (c) to examine two-occasion differences in inconsistency in these groups, and (d) to examine whether inconsistency predicts attrition in these groups.

Several expectations pertain to each study. Regarding Study 1, it is expected that mild stroke participants will show greater inconsistency compared to healthy controls based on previous findings demonstrating that neurologically-impaired adults show greater inconsistency relative to healthy adults (e.g., Hultsch et al., 2000; Stuss et al., 1994). In addition, based on previous findings (e.g., Hultsch et al., 2000; Hultsch et al., 2002; Li et al., 2001), it is expected that greater inconsistency will be associated with poorer levels of performance on cognitive tasks. Specifically, it is predicted that there will be stronger associations between greater inconsistency and poorer cognitive performance for stroke participants in comparison to healthy controls. This is because stroke patients have been shown to have increased inconsistency on RT tasks as well as deficits on the cognitive tasks used in the present thesis (i.e., episodic memory, fine-motor speed, and processing speed tasks) relative to healthy controls. Regarding Study 2, there are no specific predictions as to which group (RHD vs. LHD) will show more inconsistency, as this question is exploratory. Consistent with previous findings (i.e., Hultsch et al., 2000, 2002; Li et al., 2001), it is expected that greater intraindividual variability will be associated with poorer cognitive performance for both RHD and LHD

patient groups. However, LHD participants are expected to show more robust associations between inconsistency and cognitive performance relative to RHD participants. This prediction is based on findings showing that LHD participants have deficits in episodic memory compared to RHD participants (Mansueti et al., in preparation). In addition, since language is localized in the left-hemisphere for right-handed individuals, LHD participants are expected to perform more poorly on the processing speed tasks (which involve a language component) relative to RHD participants. Finally, since participants in this study are using their right hand, LHD participants are predicted to show worse fine-motor speed performance compared to RHD participants because most motor deficits are evident in the limb contralateral to the side of damage (Levin, 1996; Trombly, 1992). Furthermore, Wyke (1968) found that, among a group of right-handed stroke patients, LHD patients did worse relative to RHD patients on a fine-motor task involving adequate timing and precision using the right hand. Regarding Study 3, it is expected that the moderate stroke group will show more inconsistency compared to the mild and control groups. It is also expected that greater inconsistency will be associated with poorer cognitive performance, but that this association will differ as a function of severity. Specifically, it is predicted that the moderately severe stroke participants will show more robust associations than the other two groups. This is based on the expectation that the moderate group will perform more poorly on the cognitive tasks and show more inconsistency relative to the other two groups. It is also expected that inconsistency in healthy controls will increase over time, based on the findings of MacDonald, Hultsch, and Dixon (2003) which revealed that inconsistency increased over time in a longitudinal sample of healthy older adults. There

is the possibility of recovery of function for the stroke groups, based on the finding that TBI patients with a longer time since injury showed less inconsistency compared to those with a shorter time since injury (Hetherington et al., 1996). However, this study used TBI patients of a wide range of ages (i.e., 15-60 years), and thus the effects of aging on recovery is not known. Therefore, it is expected that the mild and moderate stroke groups will show increased inconsistency over time due to the effects of aging (MacDonald et al., 2003), despite any recovery of function. Finally, it is predicted that mild, moderate and control participants who have dropped out of the study will show increased inconsistency compared to those who remained in the study. This prediction is based on the finding that healthy older adults who dropped out after the first wave of testing in a longitudinal study were more inconsistent on RT tasks than those who remained in the study (MacDonald et al., 2003).

Study 1

Method

Participants

Three independent samples of community-dwelling older adults (initially between 55-90 years) are followed in the Victoria Longitudinal Study (VLS), a longitudinal-sequential study of adult development. Participants in all samples were originally recruited through media advertisements as well as appeals to community groups. They were paid a small honorarium for their participation. Whereas the first wave of testing for Sample 1 occurred in 1986-87 ($n = 484$), the first wave of testing for Sample 2 occurred in 1992-93 ($n = 530$), and the first wave of testing for Sample 3 occurred in 2002-03 ($n = 550$). There is a three-year interval between waves for all three samples. Further

information about the design, samples, and specific reasons for attrition is available elsewhere (Dixon & de Frias, 2004; Hultsch, Hertzog, Dixon, & Small, 1998).

For each wave, personal information is obtained regarding changes in health status during the intervening three years. All participants are initially ambulatory and non-institutionalized. The present study used participants from Sample 3 (Wave 1). Two groups of participants were identified for inclusion in the study. The first group consisted of participants who reported having had a mild-to-moderate stroke. Although $n = 27$ stroke participants were initially identified, four participants were excluded from the study (one participant was left-handed, another was ambidextrous, another had missing reaction time data, and for the fourth participant it was not clear whether they had a stroke or not). Of the resulting $n = 23$ participants, 69.6% reported a mild stroke and 30.4% reported a moderate stroke. Because the mild and moderate stroke participants performed similarly on almost all outcome measures (except for semantic decision and reading speed), these two groups were collapsed into one single stroke group. Mean age of onset of stroke is 68.07 years for the participants with strokes ($SD = 10.81$, range = 47.5-87.0). Mean time since stroke is 6.98 years ($SD = 5.73$, range = 0-24 years). The second group consisted of $n = 23$ individuals with no history of stroke. They were identified from the same VLS sample and were matched to stroke participants on gender, age, and education. Overall, there were $n = 46$ participants who ranged in age from 57 to 90 years (Stroke: $M = 75.04$ years, $SD = 8.73$; Controls: $M = 74.87$ years, $SD = 8.44$). There were $n = 9$ women and $n = 14$ men in each group. Average education level (in years) was similar for the stroke and control groups [Stroke: $M = 14.30$, $SD = 4.17$; Controls: $M = 14.35$, $SD = 3.32$, $t(22) = -.14$, $p = .89$]. Finally, both stroke and control

participants scored above the clinically meaningful cutoff score of 24 on the Mini-Mental State Examination (MMSE), and did not significantly differ on their MMSE scores [Stroke: $M = 28.65$, $SD = 1.50$; Control: $M = 28.52$, $SD = 1.24$, $t(22) = .28$, $p = .78$]. All participants were fluent English speakers and right-handed (stroke participants were right-hand dominant prior to stroke). Handedness was determined by self-report.

Once the stroke and matched control groups were established, analyses were conducted to see whether the groups differed on any health variables. Subjective health is a composite of two self-ratings (i.e., health relative to a perfect state; health relative to others of the same age group), and is measured on a scale from 1 (very good) to 5 (very poor). Control participants ($M = 1.65$, $SD = .57$) reported better subjective health than stroke participants [$M = 2.24$, $SD = .80$, $t(22) = 3.76$, $p = .001$]. Functional health is a composite of 8 self-ratings of how health has affected various everyday life activities (e.g., employment, doing chores). It is measured on a scale from 1 (improved) to 6 (gave up the activity). Stroke and control participants did not significantly differ on functional health ratings [Stroke: $M = 2.69$, $SD = .72$; Controls: $M = 2.51$, $SD = .84$, $t(22) = .99$, $p = .33$]. Since the stroke and control participants did not rate their health within the most severe categories (i.e., "poor" to "very poor" and "gave up the activity", for subjective and functional health, respectively), health was not believed to affect performance in the present study. Subjective sensory measures include one self-rating on vision and one on hearing relative to others of the same age group. It is measured on a scale from 1 (very good) to 5 (very poor). The groups did not differ on both the vision [Stroke: $M = 2.09$, $SD = .67$; Controls: $M = 2.00$, $SD = .74$, $t(22) = .44$, $p = .67$] and hearing [Stroke: $M = 2.30$, $SD = .93$; Controls: $M = 2.35$, $SD = 1.03$, $t(22) = -.15$, $p = .88$] self-ratings.

Measures and Procedure

The VLS measurement battery consists of multiple questionnaires, tests and tasks which assess functioning in cognitive, biological, and sensory domains (see Dixon & de Frias, in press). The test battery was administered during four testing sessions which were scheduled over a period of approximately four to six weeks. Tasks were administered in the same order for all participants.

RT Tasks

Inconsistency estimates were based on RT latencies from four multi-trial computer-based RT tasks. Two of the tasks assessed speed of responding to relatively simple nonverbal stimuli [i.e., simple reaction time (SRT) and choice reaction time (CRT)], whereas the other two assessed speed of responding to more complex language-based stimuli (i.e., lexical decision and semantic decision). For all tasks, stimuli were presented on a computer monitor interfaced with a 386-MHz IBM-compatible computer that controlled stimulus presentation and timing. Participants were required to respond to stimuli by pressing keys on a custom-designed response console. Responses were recorded at an accuracy of ± 1 ms.

Simple reaction time (SRT). For SRT, participants were presented with a warning stimulus (***) followed by a signal stimulus (+) in the center of the computer screen. Participants were required to press a key with their preferred hand as quickly as possible once the signal stimulus appeared. There were a total of 50 test trials with ten randomly arranged trials presented at each of five intervals separating the warning and signal stimuli (500, 625, 750, 875, and 1,000 ms). Outcome measures used were the latencies of each of the 50 test trials.

Choice reaction time (CRT). In the CRT task, a 3 X 3 grid matching the arrangement of keys on the response console was displayed on the computer screen. This array was used to instrument two-, four-, and eight-choice RT trials. Prior to making each response, participants placed their right forefinger in the center of the response keypad which served as the home key. A total of 60 trials (six blocks of ten trials) were administered in which participants were required to attend to either two, four, or eight squares. A warning stimulus was presented, followed (after a delay of 1,000 ms) by the appropriate two-, four-, or eight-square matrix. One square contained an *O* and all the others contained *X*s. Participants were instructed to press the key corresponding to the location of the *O* as quickly as possible. Latencies of the 60 trials were used as the outcome measures.

Lexical decision. For the lexical decision task (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985) participants were presented with a string of five to seven letters on the computer screen and were instructed to indicate as quickly as possible whether they formed an English word (e.g., *island* vs. *nabion*). Participants responded by pressing one of two keys on the response console. There were a total of 60 trials (30 words and 30 nonwords). Latencies of the 60 trials were used as the outcome measures.

Semantic decision. This task was adapted from procedures used by Palmer, MacLeod, Hunt, and Davidson (1985). Participants were asked to judge as quickly as possible the plausibility of sentences presented on the computer screen (e.g., *The tree fell to the ground with a loud crash, The pig gave birth to a litter of kittens this morning*). Participants responded by pressing one of two keys on the response console. There were

a total of 50 test sentences (25 plausible and 25 implausible). Latencies of the 50 trials served as the outcome measures.

It should be noted that RTs for both correct and incorrect responses will be used since the main interest in the present study is to examine response times and not necessarily accuracy of responses. As a check, the relative frequencies and latencies of correct and incorrect responses were compared. First, the responses were predominantly correct. Relatively few errors were found across the entire Persons X Trials data matrix for all three tasks (CRT = .65% errors; lexical decision = 1.49% errors; semantic decision = 4.26% errors) and did not differ as a function of group [CRT: $t(22) = -.94$, $p = .36$; lexical decision: $t(22) = -.13$, $p = .89$; semantic decision: $t(22) = -.48$, $p = .64$]. Second, RTs for correct and incorrect responses did not significantly differ for CRT [Correct: $M = 893.57$, $SD = 281.93$; Incorrect: $M = 1017.56$, $SD = 304.80$, $t(2758) = 1.86$, $p = .06$], but did significantly differ for both the semantic [Correct: $M = 4003.66$, $SD = 1790.38$; Incorrect: $M = 4813.12$, $SD = 2584.19$, $t(2298) = 4.28$, $p = .00$] and lexical [Correct: $M = 1224.54$, $SD = 692.15$; Incorrect: $M = 2225.51$, $SD = 1831.72$, $t(2758) = 8.82$, $p = .00$] decision tasks. Despite the robust pattern of correct responses being faster than incorrect responses, the latter were likely to have little impact on the overall data.

Cognitive Measures

Cognitive performance was assessed by using two indicators of episodic memory, two indicators of processing speed, and two indicators of fine-motor speed.

Word recall. Six categorized lists of common English nouns were developed from the Howard (1980) and Battig and Montague (1969) norms. Each list contained six words from each of five categories (e.g., *birds, flowers*) for a total of 30 words per list.

Categories and exemplars were chosen so as to minimize possible interference effects within and across lists. In general, high-frequency exemplars ranked two through nine according to the Howard (1980) and Battig and Montague (1969) norms were chosen, but to minimize guessing, the most frequently used noun was not used. Participants studied and recalled two word lists. They had two minutes to study each list, followed immediately by a 5-minute written recall test for each list. Participants were instructed to write down, in any order, as many words as they could remember. The average number of correctly recalled words across the two lists was used as the outcome measure.

Story recall. Immediate gist recall of two narrative stories describing an event in the life (lives) of an older protagonist who was either a woman, a man, or a couple was used as a second indicator of episodic memory (Dixon, Hultsch, & Hertzog, 1989; Dixon, Hertzog, Friesen, & Hultsch, 1993). The structurally equivalent stories were composed of 24 sentences, consisting of approximately 300 words which were organized into approximately 160 propositions (Dixon et al., 1989; Kintsch, 1974). Participants had four minutes to study each story (which were presented in typed booklets), and ten minutes to write their recall. Recall protocols were scored for gist recall by following the criteria described in Dixon et al. (1989). Gist recall of the average proportion of propositions (idea units) recalled across the two stories was used as the outcome measure.

Comprehension speed. For the comprehension speed task, participants were initially presented with a question on the computer screen, and then were required to search for the answer as quickly as possible in a paragraph of indeterminate length presented one sentence at a time. Sixteen passages were presented, and the timing of the task was self-paced. Total search time across all passages was the measure used.

Reading speed. In the reading speed task, participants read short narratives at their normal reading rate. Six passages were presented one sentence at a time on the computer screen, and the timing of the task was self-paced. The measure used was time per proposition.

Perceptual speed. Perceptual processing speed was assessed using the Digit Symbol Substitution task from the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1958). Participants were provided with a coding key which paired nine numbers (one through nine) with nine symbols. Rows of randomly-ordered numbers with empty boxes below them were printed under the coding key. Participants had 90 seconds to transcribe as many symbols as possible into the empty boxes based on the digit-symbol associations specified in the coding key. The outcome measure used was the number of correctly completed items.

Copying speed. Copying speed was assessed using two fine-motor tasks (Dixon, Kurzman, & Friesen, 1993). In the Backward h copying task (adapted from van Galen & Teulings, 1983), participants were required to write the letter *h* as frequently as possible in each of five periods lasting for 20 seconds. The answer sheet contained 121 possible cells for writing each lowercase *h*. Each cell of the answer sheet contained a dot indicating where to begin writing. Participants were instructed to begin writing the letter *h* at the bottom right side point of the letter. Each *h* was scored as either a perfect or a gist rendition. The number of perfect and gist (which included both perfect and gist renditions) *h*s produced in each of the five 20-second periods were used as the outcome measures. For the word copying task, participants were required to copy a series of six common words as frequently as possible within five 20-second periods. All words were

English nouns selected from the Howard (1980) norms, and were one syllable and five letters in length. This task is similar to that used by Meulenbroek and van Galen (1989). Each character was scored as either a perfect or gist character. The outcome measures used were the number of perfect and gist (which included both perfect and gist renditions) characters correctly produced in each of the five 20-second periods. Reliability estimates were derived by computing the correlation between scores for pairs of raters. There were five independent raters in total. For the *h* copying task, the average correlations were .63 (range = .43-.80) and .99 (range = .98-1.00), for perfect and gist renditions, respectively. For the word copying task, the average correlations were .65 (range = .52-.75) and .95 (range = .86-.99), for perfect and gist renditions, respectively. However, because the two raters doing the scoring for this task had a moderate correlation between their scores on gist for the word copying task, additional training was provided until a higher level of reliability was achieved. The correlation between this pair of raters was .99 on gist for the word copying task.

Data Preparation

Prior to analyzing the data, the distributions of raw latency scores for each of the RT tasks were examined for outliers. Extremely fast or slow responses might reflect various types of errors (e.g., accidental key presses or distraction of the participant), and thus were trimmed in order to minimize such influences. A lower bound for legitimate responses was set for each RT task based on previous research (e.g., Hultsch et al., 2000; MacDonald et al., 2003), and scores below this limit were dropped. The limits were as follows: SRT = 150 ms, CRT = 150 ms, lexical decision = 400 ms, and semantic decision = 1,000 ms. An upper bound was established by computing the mean and standard

deviation for both the stroke and control groups; any trials exceeding the mean by three or more standard deviations were dropped. The number of trials dropped across the entire Persons X Trials data matrix was relatively small (SRT = 1.57%; CRT = 1.09%; lexical decision = 1.78%; semantic decision = 1.61%) and was unrelated to group [SRT: $t(22) = -.29$, $p = .78$; CRT: $t(22) = -.66$, $p = .52$; lexical decision: $t(22) = .08$, $p = .94$; semantic decision: $t(22) = .23$, $p = .82$]. To avoid statistical problems with missing data, values for the outlier trials were imputed using the following procedure. Each of the RTs were regressed on Trial to check for a trial or practice effect. These analyses revealed no trial effect for SRT ($b = -.11$, $p = .53$), CRT ($b = -.46$, $p = .08$), and semantic decision ($b = -.28$, $p = .90$). Since no trials effects were found, an individual's mean RT across all remaining trials was used to impute their missing outlier trials. A trial effect was observed for lexical decision ($b = -3.59$, $p < .01$) indicating that participants' RTs decreased (i.e., participants responded faster) as trials increased. Therefore, using an individual's overall mean RT to impute missing trials was not appropriate since RTs differed from the beginning to the end of the task. Thus, the mean of nearby points (i.e., a maximum of three points before and three points after the missing value) was used to impute missing values for lexical decision. Because dropping outlier scores and imputing missing values actually reduces variability, this represents a conservative approach to examining the phenomenon of intraindividual variability.

Results

The results are presented in three main parts. First, the stroke and control groups were compared on overall level of performance on each of the RT and cognitive measures. The second set of analyses focused on group differences in intraindividual

variability on each of the RT tasks. Finally, Pearson product-moment correlations were computed separately by group in order to determine (a) intercorrelations of intraindividual variability indicators (i.e., ISDs) for the four RT tasks, and (b) relationships among intraindividual variability indicators (i.e., ISDs) for the RT tasks and level of performance on all cognitive tasks. For all the analyses, alpha levels of $p \leq .05$ were specified to indicate statistical significance.

Group Differences in Level of Performance

To examine group differences in mean level of performance on each of the RT measures and five of the cognitive measures (i.e., word recall, story recall, comprehension speed, reading speed, and perceptual speed), a series of one-way within-subjects Analyses of Variance (ANOVA) with group (stroke, control) as the within-subjects factor were conducted on each of the variables. Stroke and control participants did not significantly differ on any of the RT or cognitive measures. Refer to Table 1 for the means and standard deviations.

As previously mentioned, copying speed was assessed using the word and backward *h* copying tasks. The latter can be viewed as a relatively unfamiliar task, whereas the former can be viewed as a relatively familiar one. Accordingly, a Group (stroke, control) x Familiarity (familiar, unfamiliar) x Trial within-subjects ANOVA, with all factors as within-subjects factors, was conducted on the number of perfect characters produced and on the number of gist characters produced in order to examine group differences in copying speed. For perfect characters, analyses revealed a main effect of familiarity [$F(1, 22) = 46.73$, $p < .001$, $\eta^2 = .001$] in which participants produced more familiar ($M = 3.87$, $SD = 3.30$) than unfamiliar ($M = .69$, $SD = 1.22$) characters. A

main effect of trial was also found [$F(4, 88) = 7.41$, $p < .001$, $\eta^2 = .01$]. Refer to Table 2 for the means and standard deviations. Post hoc comparisons revealed no significant differences in the number of perfect characters produced across trials 1 to 4. However, participants produced significantly more perfect characters on trial 4 compared to trial 5. Finally, participants produced significantly more perfect characters on trial 1 compared to trial 5. For gist characters, analyses revealed a main effect of familiarity [$F(1, 22) = 431.27$, $p < .001$, $\eta^2 = .0004$] in which participants produced more familiar ($M = 43.09$, $SD = 9.05$) than unfamiliar ($M = 17.01$, $SD = 4.13$) characters. A main effect of trial was also found [$F(4, 88) = 18.25$, $p < .001$, $\eta^2 = .01$]. See Table 2 for the means and standard deviations. Post hoc comparisons revealed that participants produced more gist characters on trial 2 relative to trial 1; the number of gist characters produced across trials 2 to 5 did not significantly differ. Finally, participants produced significantly more gist characters on trial 5 compared to trial 1.

In addition to examining group differences in overall mean level of RT performance, group differences across trials for all four RT tasks were also examined. Specifically, the mean RTs for the first ten trials, the middle ten trials, and the last ten trials were computed for each of the RT measures, creating three blocks of trials. Accordingly, a series of Group (stroke, control) x Block (first, second, third) within-subjects ANOVAs, with both factors as within-subjects factors, were conducted on each of the RT measures. Overall, no significant group effects or interactions were observed. Refer to Table 3 for the means and standard deviations for all four RT tasks. For SRT, a main effect of block was found [$F(2, 44) = 5.15$, $p = .01$, $\eta^2 = .04$]. Post hoc comparisons revealed that participants had longer RTs on the first block of trials compared to the

second block of trials. In addition, participants had longer RTs on the third block of trials compared to the second block of trials. For CRT, a main effect of blocks was found [$F(2, 44) = 20.92, p < .001, \eta^2 = .17$]. Post hoc comparisons revealed that participants had faster RTs on the first block compared to the second block and the third block of trials. For lexical decision, a main effect of blocks was found [$F(2, 44) = 27.65, p < .001, \eta^2 = .17$]. Post hoc comparisons revealed that participants responded faster on the second block compared to the first block of trials. In addition, participants were faster on the third block in comparison to the second block of trials. For semantic decision, a main effect of blocks was found [$F(2, 44) = 9.88, p < .001, \eta^2 = .04$]. Post hoc comparisons revealed that participants were faster on the second block compared to the first block of trials, and that they were faster on the third block relative to the second block of trials. It should be noted that for SRT and CRT it was found that participants had longer RTs as trials increased, which is opposite to what the regression analyses checking for a trials effect revealed. Although the regression analyses for SRT and CRT were both nonsignificant, these analyses revealed that the slope was negative for both tasks, indicating a tendency for participants to have faster RTs as trials increased. These analyses may be contradictory because only a subset of selected RT trials were used in the ANOVAs presented here, which did not follow the same pattern as the regression analyses in which all RT trials were used.

Group Differences in Intraindividual Variability

Indexing Performance Inconsistency. Multiple indices can be computed to examine intraindividual variability (Slifkin & Newell, 1998). Perhaps the simplest of these is the intraindividual standard deviation (ISD) computed across trials. However,

computing ISDs on raw scores is problematic for the following reasons. First, there are usually significant group differences observed in average level of performance for most cognitive measures. Second, there may be systematic changes over time (e.g., trials), such as practice and learning-to-learn effects. Such group and systematic time-related effects are potential confounds when examining intraindividual variability because larger standard deviations are usually associated with larger means (for distributions and scales in which larger means indicate poorer performance). For example, older adults may have higher average ISDs relative to younger adults simply as a consequence of their slower (longer) RT latencies. Similarly, practice effects may also play a role in raw score differences in inconsistency. Clearly, it is crucial to account for both group differences and systematic time-related effects in order to get an accurate estimate of intraindividual variability in performance.

To address these concerns, the effects associated with group, trial, and all their interactions were partialed from the raw data prior to computing ISDs. This procedure yielded residual scores that were independent of group differences in response speed as well as any systematic variation due to influences such as practice. These purified scores were then standardized as *T* scores (all groups having $M = 50$ and $SD = 10$) to allow for comparisons in the same metric across tasks. These purified residual *T* scores were then used to compute ISDs for each of the RT tasks.

In order to examine whether stroke and control groups differed in intraindividual variability a series of one-way within-subjects ANOVAs, with group (stroke, control) as the within-subjects factor, were computed on ISDs on all four RT measures. Stroke and control groups did not significantly differ in ISDs for SRT [stroke: $M = 8.66$, $SD = 3.53$;

control: $M = 7.41$, $SD = 1.68$, $F(1, 22) = 2.04$, $p = .17$, $\eta^2 = .05$], lexical decision [stroke: $M = 7.63$, $SD = 2.79$; control: $M = 7.42$, $SD = 2.50$, $F(1, 22) = .06$, $p = .80$, $\eta^2 = .002$], or semantic decision [stroke: $M = 7.14$, $SD = 1.71$; control: $M = 6.77$, $SD = 1.62$, $F(1, 22) = .73$, $p = .40$, $\eta^2 = .01$]. However, stroke participants ($M = 8.38$, $SD = 1.81$) had significantly higher ISDs than healthy controls ($M = 7.33$, $SD = 1.28$) on the CRT task [$F(1, 22) = 5.87$, $p = .02$, $\eta^2 = .11$], indicating that stroke participants were more variable on CRT compared to control participants. Refer to Figure 1 for a graphical representation of CRT residual latency T scores across trials for the stroke and control groups.

Correlational Analyses Between Intraindividual Variability and Cognitive Performance

A series of Pearson product-moment correlations were performed separately by group in order to examine (a) intercorrelations of intraindividual variability indicators (i.e., ISDs) for the four RT tasks, and (b) relationships among intraindividual variability indicators (i.e., ISDs) for the four RT tasks and mean level of performance on all cognitive tasks.

Intercorrelations between the ISD scores for the RT tasks for stroke and control groups are shown in Tables 4 and 5, respectively. In general, increased variability on one RT task was associated with increased variability on another task for both the stroke and control groups, although there were a few exceptions to this pattern. Despite the small number of significant correlations, the magnitude of the correlations going in the expected direction was quite high and ranged from .19-.55 for the stroke group and .15-.60 for the control group.

In order to compare the stroke and control groups on the robustness of the relationship between ISD scores, each of the correlations between the ISDs on RT tasks

were converted to *z*-scores using Fisher's *r* to *z* transformation. The overall average across all four RT tasks was then computed separately for the stroke and control groups. Analyses revealed that the stroke (mean $r = .29$) and control (mean $r = .22$) groups did not significantly differ from each other in the strength of the relationship between ISDs on RT tasks ($z = .23$, $p = .41$).

Correlations between individual mean level of performance and ISD scores for stroke and control participants are shown in Tables 6 and 7, respectively. Both tables display information on relationships between variability and mean level of performance on the RT and all cognitive tasks. For both groups the pattern of correlations reveals that increased variability is associated with poorer level of cognitive performance, although not all correlations reached statistical significance. This relationship, however, holds for more measures for the stroke participants (i.e., 88.5% of the correlations were in the expected direction) compared to the control participants (i.e., 73.1% of the correlations were in the expected direction). Finally, the magnitude of the correlations in the expected direction was quite high for both groups and ranged from .02-.85 for the stroke group and .01-.83 for the controls.

Comparing the groups on the robustness of the relationship between ISD scores and mean level of performance was accomplished by converting the correlations to *z*-scores, as described above. The various measures were grouped and the average correlation across all four measures of variability was computed separately for the stroke and control groups. Measures were grouped as follows: RT (composed of SRT, CRT, lexical and semantic decision), episodic memory (composed of word and story recall), processing speed (composed of comprehension and reading speed), and fine-motor speed

(composed of perceptual speed and copying speed—gist only). Analyses revealed that the stroke (mean $r = .33$) and control (mean $r = .31$) groups did not significantly differ in the robustness of the relationship between ISDs and RT tasks ($z = .10$, $p = .46$). For both groups, the mean correlations reveal that increased variability is associated with increased RT (or, poorer performance). For episodic memory, the groups did not differ in the strength of the relationship (stroke: mean $r = -.32$; control: mean $r = -.33$, $z = .03$, $p = .49$). The mean correlations reveal that increased variability is associated with poorer episodic memory performance for both groups. The groups were also similar in the strength of the relationship for processing speed (stroke: mean $r = .37$; control: mean $r = .20$, $z = .59$, $p = .28$). In general, the mean correlations show that increased variability is associated with longer processing speed time (or, worse performance) for both groups. Finally, for fine-motor speed, the groups did not significantly differ in the robustness of the relationship (stroke: mean $r = -.24$; control: mean $r = -.09$, $z = -.48$, $p = .32$). Mean correlations reveal that, for both groups, increased variability is associated with poorer fine-motor speed performance, although this relationship was relatively weak for the control group. Overall, no significant group differences were found in the strength of the relationship for any of the measures. However, the mean correlations for all measures were in the expected direction of increased variability being associated with poorer cognitive performance.

Discussion

Although the study of intraindividual variability has included populations with compromised neurological functioning such as traumatic brain injury, dementia, and Alzheimer's disease patients, no other studies to date have examined intraindividual

variability in stroke patients and healthy controls. Accordingly, the present study extends the study of intraindividual variability by examining the performance of mild stroke and healthy control participants. No group differences were found at the mean level of performance for both the RT tasks and cognitive tasks.

The focus of the present study was intraindividual variability in performance in mild stroke and control groups. Interestingly, although no significant group differences were found in intraindividual variability for SRT, lexical, or semantic decision tasks there was a tendency for the stroke participants to show more inconsistency relative to controls on these tasks. The groups were found to differ in intraindividual variability on CRT, with the stroke group showing greater variability than the control group. Therefore, using a measure such as intraindividual variability was sensitive enough to detect group differences in CRT performance despite the fact that no group differences emerged at the overall mean level of performance. This finding suggests that mild stroke affects consistency in performance on more complex motor tasks, such as CRT, as opposed to more language-based tasks, such as lexical and semantic decision. It is important to know that mild stroke patients have greater variability on more complex motor tasks because this could have implications for future studies using such RT tasks with this population.

The pattern of correlations revealed that, for both groups, greater variability on RT tasks is associated with poorer mean level performance on the same task, as well as on other RT and cognitive tasks, replicating previous findings (e.g., Hultsch et al., 2000; Hultsch et al., 2002), and extending to a new population of stroke participants. In addition, contrary to what was expected, the mild stroke and control groups did not differ in the strength of the relationship between variability and cognitive performance. These

correlational results demonstrate that intraindividual variability on a given RT task is associated with overall mean level of performance on that task and other RT and cognitive tasks for stroke and control participants. Furthermore, intercorrelations between ISDs on all four RT tasks revealed that there was a tendency for individuals who were more variable on one RT task to be more variable on another RT task. This was true for both the mild stroke and healthy control groups. These findings show that some individuals are consistently more variable in their performance on RT tasks than others. Such findings suggest that intraindividual variability is a stable characteristic of individuals, which is consistent with other studies (e.g., Fuentes et al., 2001; Hultsch et al., 2000).

The present study represents the first attempt to compare mild stroke and healthy controls on performance inconsistency and revealed that mild stroke participants demonstrated more variability compared to healthy controls on CRT, but not on SRT, lexical, or semantic decision tasks. It was also shown for both groups that (a) greater variability on RT tasks is related to poorer mean level of performance on that same task, as well as on other RT and cognitive tasks, and (b) greater variability on one RT task is associated with greater variability on other RT tasks. It is not entirely clear why the mild stroke and control participants did not differ in intraindividual variability on SRT, lexical, or semantic decision tasks. One possibility is that mild strokes do not result in impairments in reaction time, or in inconsistency in reaction time, at least for these three RT tasks. Perhaps differences would have emerged if participants with more severe stroke had been used in the present study. Another possibility is that a mild stroke alone may not be enough to result in inconsistent performance on these RT tasks. Specifically,

it may be the case that the combined effects of having a mild stroke and cognitive impairment would result in performance inconsistency. Although the participants in the present study were all dementia-free, they were not formally screened for cognitive impairment. However, since the mild stroke and control groups had similar mean level performance on all measures, it is highly unlikely that they had cognitive impairment. An alternative, which cannot be ruled out is that inconsistency may be due to cognitive impairment and not necessarily mild stroke per se, as the findings of Ballard et al. (2003) seem to suggest. Yet another possibility is that group differences in inconsistency may have been occluded by varying time since stroke in the stroke group. That is, the mild stroke group in the present study was composed of individuals with a wide range of times since stroke, which ranged from 0-24 years since stroke. This could have posed a problem in finding group differences because previous studies have shown that TBI patients with longer times since injury have less inconsistency in performance relative to TBI patients with shorter times since injury (Hetherington et al., 1996; Stuss et al., 1989). Clearly, using a heterogeneous mild stroke group in which individuals presented at varying points in the recovery phase could have had an impact on not finding group differences. To check whether time since stroke affected performance inconsistency, time since stroke (in years) and ISDs for each of the RT tasks were correlated separately. Although none of the correlations reached statistical significance, the magnitude of the correlations was relatively high for SRT ($r = .26$) and semantic decision ($r = .37$) tasks. In contrast, the correlations for CRT ($r = .13$) and lexical decision ($r = .06$) were relatively weaker. The analyses revealed that, in general, greater time since stroke was associated with greater inconsistency. These results indicate that time since stroke had an impact on

the stroke participants' performance inconsistency, and is one reason no differences in inconsistency were found. A final possibility is that group differences in variability may have been masked by differing lesion laterality in the stroke group. That is, the stroke group in this study was comprised of individuals with both right- and left-hemisphere strokes. Given that inconsistency may distinguish between different forms of brain damage (e.g., Murtha et al., 2002), it is reasonable that inconsistency may differ as a function of lesion laterality. Accordingly, the purpose of Study 2 is to investigate this issue.

Study 2

It was demonstrated in Study 1 that stroke participants show more inconsistency on a choice reaction time task relative to healthy controls, but that the groups do not differ in inconsistency on simple reaction time, lexical decision, or semantic decision tasks. An interesting question is whether inconsistency in performance varies as a function of lesion laterality. Although no other studies to date have directly explored this question, some preliminary findings suggest that intraindividual variability may differentiate between different forms of brain damage. For example, frontal lobe dementia patients have been found to have greater inconsistency in performance relative to individuals diagnosed with dementia of the Alzheimer's type (Murtha et al., 2002). Given this finding, the purpose of the present study is to explore whether right-hemisphere damaged (RHD) and left-hemisphere damaged (LHD) stroke participants differ in performance inconsistency. Specifically, the goals of Study 2 are: (a) to investigate whether RHD and LHD participants differ in their level of inconsistency, and

(b) to explore whether performance inconsistency is associated with cognitive performance differentially for the RHD and LHD groups.

There are no specific predictions as to which group will demonstrate greater inconsistency because this question is exploratory. Based on previous findings (e.g., Hultsch et al., 2000, 2002) it is expected that greater intraindividual variability will be associated with poorer cognitive performance for both RHD and LHD groups However, LHD participants are expected to show more robust associations between inconsistency and poorer cognitive performance compared to RHD participants. This expectation is based on the finding that LHD participants have deficits in episodic memory relative to RHD participants (Mansueti et al., in preparation). Moreover, LHD participants are expected to perform more poorly on the processing speed tasks (which involve a language component) compared to RHD participants since language is localized in the left-hemisphere for right-handed individuals. Finally, the LHD group is predicted to show inferior fine-motor speed performance relative to the RHD group because motor deficits have been found in the limb contralateral to the side of damage (Levin, 1996; Trombly, 1992). In addition, LHD participants did worse than RHD participants on a fine-motor task (Wyke, 1968).

Method

Participants

Participants in this study consisted of a sub-sample of individuals from VLS Sample 3 (Wave 1) used in Study 1. Specifically, the laterality of the stroke for the $n = 23$ stroke participants was inferred on the basis of self-reported behavioral measures. Four items from the VLS (Sample 3) personal information questionnaire were used to sort the

stroke participants into provisional categories of right-hemisphere damage (RHD) or left-hemisphere damage (LHD). Participants indicated whether they had experienced any of the following conditions related to their stroke, and where applicable, which side of the body was affected: (a) language problems, (b) loss of feeling in any part of the body, (c) loss of movement in any part of the body, and (d) difficulty seeing or attending to objects on one side of the body. Participants were classified as having RHD if they indicated at least one impairment on the left side of their body; the reverse is true for those who were classified as having LHD. Ten RHD and four LHD participants were identified; $n = 9$ participants were unclassified. Sixty percent of the RHD and 75% of the LHD participants reported having had a mild stroke; the remainder reported having had a moderate stroke. As a check to determine whether the mild and moderate stroke participants could be combined into one RHD group, the mild and moderate participants were compared on all outcome measures. Because analyses revealed that the mild and moderate participants performed similarly on all outcome measures, except for reading speed, the groups were combined into one single RHD group. For the LHD group only one participant reported a moderate stroke. Therefore, the moderate stroke participants' performance was compared to the mean performance of the three mild participants. The moderate stroke participant performed within one standard deviation of the mild stroke participants on most measures, with the exception of four tasks: simple reaction time, semantic decision, reading speed, and perceptual speed. Accordingly, the mild and moderate participants were collapsed to form one single LHD group. The RHD and LHD groups did not differ on mean age of onset of stroke [RHD: $M = 64.95$ years, $SD = 9.56$, range = 47.5-77.0; LHD: $M = 72.75$ years, $SD = 10.08$, range = 64.0-85.0, $t(12) = -1.36$,

$p = .20$], or on mean time since stroke [RHD: $M = 6.95$ years, $SD = 6.89$, range = 0-24; LHD: $M = 6.00$ years, $SD = 4.62$, range = 2-10, $t(12) = .25$, $p = .81$]. RHD and LHD participants also did not differ on mean age [RHD: $M = 71.90$ years, $SD = 9.07$, range = 57-83; LHD: $M = 78.75$ years, $SD = 5.91$, range = 74-87, $t(12) = -1.38$, $p = .19$], average education level [RHD: $M = 13.50$ years, $SD = 4.03$, range = 8-19; LHD: $M = 14.50$ years, $SD = 2.38$, range = 12-17, $t(12) = -.46$, $p = .66$], or on MMSE score [RHD: $M = 28.50$, $SD = 1.78$; LHD: $M = 29.50$, $SD = .58$, $t(12) = -1.08$, $p = .30$]. The RHD group was comprised of $n = 7$ women and $n = 3$ men; the LHD group was comprised entirely of men (i.e., $n = 4$). All participants were fluent English speakers and reported being right-hand dominant prior to their stroke.

After establishing the RHD and LHD groups, analyses were conducted in order to see whether the groups differed on any important health variables. No group differences were found for subjective health [RHD: $M = 2.10$, $SD = .97$; LHD: $M = 2.25$, $SD = .65$, $t(12) = -.28$, $p = .78$] or functional health [RHD: $M = 2.68$, $SD = .85$; LHD: $M = 2.36$, $SD = .53$, $t(12) = .71$, $p = .49$]. Finally, RHD and LHD groups had similar subjective sensory self-ratings for both vision [RHD: $M = 1.90$, $SD = .57$; LHD: $M = 2.25$, $SD = .96$, $t(12) = -.86$, $p = .41$] and hearing [RHD: $M = 1.90$, $SD = .88$; LHD: $M = 2.50$, $SD = .58$, $t(12) = -1.25$, $p = .24$].

Measures and Procedure

The same measures and procedure used in Study 1 were also used in the present study. As in Study 1, both correct and incorrect RTs (in ms) were used. RTs for correct and incorrect responses did not significantly differ for CRT [Correct: $M = 877.74$, $SD = 331.46$; Incorrect: $M = 1183.00$, $SD = 342.24$, $t(838) = -1.30$, $p = .19$] or semantic

decision [Correct: $M = 4029.21$, $SD = 1815.84$; Incorrect: $M = 4522.00$, $SD = 2134.91$, $t(698) = -1.32$, $p = .19$], but did significantly differ for lexical decision [Correct: $M = 1241.65$, $SD = 682.78$; Incorrect: $M = 1802.80$, $SD = 931.82$, $t(838) = -2.57$, $p = .01$]. Overall, relatively few errors were found across the entire Persons X Trials data matrix for all three tasks (CRT = .24% errors; lexical decision = 1.19% errors; semantic decision = 3.57% errors) and did not differ as a function of group [CRT: $t(12) = -.68$, $p = .51$; lexical decision: $t(12) = -.10$, $p = .92$; semantic decision: $t(12) = 1.01$, $p = .33$]. Although there was a robust pattern of correct responses being faster than incorrect responses, the latter were likely to have little impact on the overall data given the low frequency of such responses.

Data Preparation

The same data preparation procedure used in Study 1 was used in the present study. The number of trials dropped across the entire Persons X Trials data matrix was relatively small (SRT = 1.71%; CRT = 1.19%; lexical decision = 1.90%; semantic decision = 2.14%) and was unrelated to group [SRT: $t(12) = .18$, $p = .86$; CRT: $t(12) = .83$, $p = .42$; lexical decision: $t(12) = .83$, $p = .42$; semantic decision: $t(12) = 1.02$, $p = .33$]. Values for the outlier trials were imputed using the same procedure outlined in Study 1. Analyses revealed no trial effect for SRT ($b = -.03$, $p = .96$), CRT ($b = -.31$, $p = .53$), and semantic decision ($b = -2.05$, $p = .59$). Accordingly, an individual's mean RT across all remaining trials was used to impute their missing outlier trials. A trial effect was found for lexical decision ($b = -4.20$, $p < .01$) indicating that participants responded faster as trials increased. For this task the mean of nearby points (i.e., a maximum of

three points before and three points after the missing value) was used to impute missing values.

Results

The results are presented in three main parts. First, the RHD and LHD groups were compared on overall level of performance on the RT and cognitive measures. Second, the RHD and LHD groups were compared on intraindividual variability on each of the RT tasks. Third, Pearson product-moment correlations were performed separately by group to determine (a) intercorrelations of intraindividual variability indicators (i.e., ISDs) for the four RT tasks, and (b) relationships among intraindividual variability indicators (ISDs) for the RT tasks and mean level of performance on all cognitive tasks. For all the analyses, alpha levels of $p \leq .05$ were specified to indicate statistical significance.

RHD-LHD Differences in Level of Performance

To compare RHD and LHD participants on their mean level of performance on each of the RT and five of the cognitive measures (i.e., word recall, story recall, comprehension speed, reading speed, and perceptual speed), a series of one-way between-subjects ANOVAs, with group (RHD, LHD) as the between-subjects factor, were computed on each of the variables. RHD and LHD participants did not significantly differ on any of the RT or cognitive measures. Refer to Table 8 for the means and standard deviations as a function of group.

In order to examine group differences in copying speed performance, a Group (RHD, LHD) x Familiarity (familiar, unfamiliar) x Trial ANOVA, with familiarity and trial as the within-subjects factors and group as the between-subjects factor, was

performed on the number of perfect characters produced, and on the number of gist characters produced. For perfect characters, a main effect of familiarity was found [$F(1, 12) = 9.65, p = .01, \eta^2 = .16$], revealing that participants produced more familiar ($M = 3.21, SD = 3.05$) than unfamiliar ($M = .58, SD = .89$) characters. No significant effects of group, trial, or any interactions were found. For gist characters, a main effect of familiarity was found [$F(1, 12) = 168.58, p < .001, \eta^2 = .76$] demonstrating that participants produced more familiar ($M = 44.37, SD = 7.19$) than unfamiliar ($M = 16.14, SD = 4.65$) characters. A main effect of trial was also found [$F(4, 48) = 7.75, p < .001, \eta^2 = .01$]. Post hoc comparisons revealed that participants produced more gist characters at trial 2 ($M = 29.69, SD = 6.90$) compared to trial 1 ($M = 27.81, SD = 4.89$), and more gist characters at trial 3 ($M = 31.10, SD = 5.98$) compared to trial 2. Participants also produced more gist characters at trial 5 ($M = 31.75, SD = 5.70$) compared to trial 4 ($M = 30.90, SD = 6.14$). Finally, participants produced more gist characters at trial 5 relative to trial 1. No significant main effect of group or any interactions were found.

A series of Group (RHD, LHD) x Block (first, second, third) ANOVAs, with group as the between-subjects factor and block as the within-subjects factor, were performed on each of the RT measures. Refer to Table 9 for the means and standard deviations. A main effect of block was found for CRT [$F(2, 24) = 14.34, p < .001, \eta^2 = .48$], lexical decision [$F(2, 24) = 10.04, p = .001, \eta^2 = .34$], and semantic decision [$F(2, 24) = 5.12, p = .01, \eta^2 = .24$]. Post hoc comparisons revealed the same pattern of findings for all three RT tasks. Specifically, participants took longer on block 3 relative to block 1. In addition, participants took longer on block 3 than block 2, and took longer on block 2 than block 1. No significant group effects or interactions were found for these

three RT tasks, and no significant group, block, or interaction effects were found for SRT. It should be noted that for CRT it was found that participants had longer RTs as trials increased, which is opposite to what the regression analysis checking for a trials effect revealed. Although the regression analysis for CRT was nonsignificant, this analysis revealed that the slope was negative, indicating a tendency for participants to have faster RTs as trials increased. These analyses may be contradictory because only a subset of selected RT trials were used in the ANOVA presented here, which did not follow the same pattern as the regression analysis in which all RT trials were used.

RHD-LHD Differences in Intraindividual Variability

Intraindividual variability was indexed using ISDs which were computed by following the same procedure as outlined in Study 1. To account for any systematic and group differences, the effects associated with age, gender, group, trial, and all their interactions were partialed from the raw data prior to computing ISDs.

A series of one-way between-subjects ANOVAs with group (RHD, LHD) were conducted on ISDs on all four RT measures to determine whether the groups differed in intraindividual variability. RHD and LHD patient groups did not significantly differ in intraindividual variability on SRT [RHD: $M = 8.90$, $SD = 4.37$; LHD: $M = 10.37$, $SD = 3.30$, $F(1, 12) = .37$, $p = .56$, $\eta^2 = .03$], CRT [RHD: $M = 9.82$, $SD = 2.16$; LHD: $M = 10.02$, $SD = 2.15$, $F(1, 12) = .03$, $p = .88$, $\eta^2 = .002$], lexical decision [RHD: $M = 10.40$, $SD = 3.63$; LHD: $M = 7.31$, $SD = 1.69$, $F(1, 12) = 2.58$, $p = .14$, $\eta^2 = .02$], or semantic decision [RHD: $M = 9.70$, $SD = 2.54$; LHD: $M = 10.15$, $SD = 2.34$, $F(1, 12) = .09$, $p = .77$, $\eta^2 = .01$].

Correlational Analyses Between Intraindividual Variability and Cognitive Performance

Pearson product-moment correlations were computed separately by group in order to examine (a) intercorrelations of intraindividual variability indicators (i.e., ISDs) for the four RT tasks, and (b) relationships among intraindividual variability indicators (i.e., ISDs) for the four RT tasks and mean level of performance on all cognitive tasks.

Intercorrelations between ISD scores on the four RT tasks for RHD and LHD participants are displayed in Tables 10 and 11, respectively. Although there were some exceptions, these data reveal a tendency for increased variability on one task to be associated with increased variability on another task for both RHD and LHD groups. Although there were no significant correlations, the magnitude of correlations in the expected direction was relatively high and ranged from .34-.57 for the RHD group and .16-.63 for the LHD group.

To compare the RHD and LHD groups on the robustness of the relationship between ISD scores, the same procedure as outlined in Study 1 was followed. Analyses revealed that the RHD (mean $r = .16$) and LHD (mean $r = .25$) groups did not significantly differ from each other ($z = -.08$, $p = .47$) in the strength of the relationship between variability on RT tasks.

Correlations between mean level of performance and ISD scores for RHD and LHD groups are shown in Tables 12 and 13, respectively. In general, the pattern of correlations shows that increased variability is associated with poorer level of cognitive performance for both groups, although not all correlations were found to be significant. This negative relationship appears to hold for more measures for the RHD participants (i.e., 80.8% of the correlations were in the expected direction) relative to the LHD

participants (i.e., 46.2% of the correlations were in the expected direction). The magnitude of the correlations in the expected direction was quite high for both groups and ranged from .01-.90 for the RHD group and .04-.97 for the LHD group.

In order to examine differences between the RHD and LHD groups on the strength of the relationship between ISDs and mean level of performance, the same procedure as outlined in Study 1 was followed. For RT tasks, the groups did not differ in the strength of the relationship between ISDs and RT tasks (RHD: mean r = .42; LHD: mean r = -.08, z = .50, p = .31), although there is a large difference between these mean correlations. Despite the large difference, these mean correlations did not significantly differ from each other because the critical value of z = 1.65 was not reached. The mean correlations show different patterns for the groups. Specifically, increased variability is associated with increased (or, longer) RTs for the RHD group, whereas for the LHD group there was a relatively weak association between increased variability and decreased (or, faster) RTs. For episodic memory, the groups did not significantly differ in the strength of the relationship (RHD: mean r = -.35; LHD: mean r = .47, z = -.82, p = .21). Despite a large difference between the mean correlations, the critical value of z = 1.65 was not reached. For the RHD group, the mean correlation shows that increased variability is associated with poorer episodic memory. The mean correlation for the LHD group shows that increased variability is associated with better episodic memory performance. The groups were similar in the strength of the relationship for processing speed (RHD: mean r = .30; LHD: mean r = .37, z = -.08, p = .47). Overall, increased variability is associated with longer processing speed time for both groups. Finally, for fine-motor speed, the groups did not significantly differ in the strength of the relationship

(RHD: mean r = -.33; LHD: mean r = -.17, z = -.16, p = .44). In general, the mean correlations reveal that increased variability is associated with poorer fine-motor speed performance for both RHD and LHD groups.

Discussion

The major aim of this study was to investigate whether intraindividual variability varies as a function of lesion laterality in stroke participants. Some preliminary findings suggest that inconsistency in performance may be sensitive enough to distinguish between different forms of brain damage (e.g., Murtha et al., 2002), but no other studies have directly explored the question of whether intraindividual variability in performance varies in RHD versus LHD stroke patients. Stroke participants from Study 1 were classified as having either a right- or left-hemisphere stroke based on behavioral self-report measures.

The RHD and LHD groups did not differ in the overall mean level of performance on RT or cognitive tasks. The groups also did not differ in levels of inconsistency on the RT tasks. These null results are most likely due to the small sample sizes used in the present study (i.e., RHD: n = 10; LHD: n = 4), especially for the LHD group. Although the groups did not significantly differ in intraindividual variability, an inspection of the means for each of the groups reveals a tendency for the LHD group to show slightly higher levels of inconsistency relative to the RHD group on SRT (RHD: M = 8.90; LHD: M = 10.37), CRT (RHD: M = 9.82; LHD: M =10.02), and semantic decision (RHD: M = 9.70; LHD: M = 10.15). Perhaps with larger sample sizes group differences in inconsistency will emerge, as this trend seems to suggest.

The pattern of correlations showed that, in general, greater inconsistency is associated with poorer mean level of performance on that same task, in addition to other RT and cognitive tasks for the RHD and LHD groups. This finding is consistent with the finding in Study 1, as well as other studies (e.g., Hultsch et al., 2000; Hultsch et al., 2002). Two exceptions to this general pattern should be noted. The mean correlations computed between (a) ISDs and RT performance, and (b) ISDs and episodic memory performance showed the opposite pattern for only the LHD participants. That is, these mean correlations revealed that increased variability is weakly associated with faster RTs (or, better performance) and that increased variability is associated with better episodic memory performance. It is not clear why these two exceptions emerged. Further studies with larger LHD groups may help to clarify this finding. Except for these two anomalies, the other mean correlations were in the expected direction for both groups. In addition, the RHD and LHD groups did not differ in the strength of the relationship between variability and cognitive performance, contrary to what was predicted. Despite these null findings, there were two cases (i.e., the correlations between ISDs and RT performance and ISDs and episodic memory performance) in which there were large differences in the correlations for the RHD and LHD groups, suggesting that this is an interesting area for future study. Taken together, these correlational results indicate that intraindividual variability on a given RT task is associated with overall mean level of performance on that task as well as other RT and cognitive tasks for RHD and LHD participants. Moreover, intercorrelations between ISDs on the four RT tasks showed that there is a trend for those individuals who were more variable on one RT task to also be more variable on another RT task. This pattern held for both RHD and LHD participants. Thus,

it appears that some individuals are consistently more variable than others, which suggests that inconsistency is a stable characteristic in individuals. These findings replicate the findings of Study 1, as well as those of previous studies (e.g., Fuentes et al., 2001; Hultsch et al., 2000).

Study 3

Although inconsistency was not found to differ as a function of laterality, another interesting question is whether inconsistency varies as a function of stroke severity. Despite the fact that other studies have not found inconsistency to be useful in distinguishing between levels of severity in TBI patients (Burton et al., 2002; Stuss et al., 1994), no studies have explored whether stroke severity affects performance inconsistency. Accordingly, exploring the impact of stroke severity on inconsistency is one of the goals of the present study. Another major goal of the present study is to examine longitudinal changes in inconsistency. Only one other study by MacDonald et al. (2003) has examined changes in inconsistency over time. In this study, it was found that inconsistency increases over time in healthy older adults. It was also revealed that those individuals who did not continue to participate showed greater inconsistency than those who continued to participate. The goals of Study 3 include: (a) to examine whether mild, moderate, and control participants differ in performance inconsistency, (b) to investigate whether inconsistency is related to cognitive performance differentially for the three groups, (c) to explore longitudinal changes in inconsistency for the groups, and (d) to examine whether those individuals who did not continue to participate show more inconsistency relative to those who continued to participate.

Regarding group differences in inconsistency, the moderate stroke group is expected to show more inconsistency than the mild and control groups. It is also predicted that greater inconsistency will be related to poorer cognitive performance, but that this relationship will be stronger for the moderate stroke group relative to the other two groups. This is based on the expectation that moderate stroke participants will perform more poorly on the cognitive tasks and will also show more inconsistency compared to the other groups. Regarding longitudinal changes in inconsistency, it is predicted that healthy controls will show greater inconsistency over time based on the findings of MacDonald et al. (2003). Regarding the mild and moderate stroke groups, it could be argued that there may be the possibility of recovery of function over time, based on the finding that TBI patients (aged 15-60 years) with a longer time since injury showed less inconsistency compared to those with a shorter time since injury (Hetherington et al., 1996). Consequently, inconsistency would be expected to decrease over time for both stroke groups. However, the effects of aging-related increases in inconsistency over time must also be accounted for, and since Hetherington et al. (1996) used TBI patients of varying ages (i.e., 15-60 years), the recovery process in older adults is not known. Therefore, it is predicted that despite any recovery of function, inconsistency in the mild and moderate stroke groups will increase over time due to the effects of aging. Finally, based on previous findings (MacDonald et al., 2003), it is expected that those participants who have not continued to participate will show more inconsistency compared to those who have continued to participate.

Method

Participants

Participants in this study included individuals initially from VLS Sample 1 (Wave 2) and Sample 2 (Wave 1). Two groups of participants were identified for inclusion in the present study. The first group consisted of individuals who reported having a mild-to-moderate stroke. Initially, $n = 24$ participants were identified, however two participants were excluded due to missing RT data. Of the remaining $n = 22$ participants, $n = 17$ reported a mild stroke and $n = 5$ indicated a moderate stroke. The second group of participants consisted of $n = 22$ healthy control participants from VLS Samples 1 (Wave 2) and 2 (Wave 1). Thus, the present sample consisted of $n = 44$ participants and represented the first occasion of measurement for this longitudinal sample. The second occasion of measurement included those participants from the first occasion who continued to participate at the next consecutive Wave [i.e., Sample 1 (Wave 3) and Sample 2 (Wave 2)]. A total of $n = 30$ participants ($n = 13$ mild; $n = 3$ moderate; $n = 14$ healthy controls) were included in the subsample for Occasion 2.

Descriptive information on the participants' age, gender, education, self-reported health, hearing, vision and stroke severity (where applicable) is reported in Tables 14 and 15 for Occasions 1 and 2, respectively. For Occasion 1, mild, moderate, and control participants did not differ in age [$F(2, 41) = .14$, $p = .87$], years of education [$F(2, 41) = .16$, $p = .86$], subjective health [$F(2, 41) = 2.89$, $p = .07$], hearing [$F(2, 41) = .22$, $p = .81$] or vision [$F(2, 41) = .02$, $p = .98$]. The groups significantly differed on their functional health ratings [$F(2, 41) = 7.05$, $p < .01$], with moderate stroke participants reporting worse functional health than both the mild and healthy controls; the latter two groups did

not significantly differ in their self-ratings. For Occasion 2, the mild, moderate, and control participants did not differ in age [$F(2, 27) = 2.71$, $p = .08$], average education level (in years) [$F(2, 27) = .82$, $p = .45$], subjective health ratings [$F(2, 27) = 3.03$, $p = .07$], or hearing [$F(2, 27) = 2.36$, $p = .11$]. The groups significantly differed on functional health [$F(2, 27) = 7.17$, $p < .01$], and vision [$F(2, 27) = 4.45$, $p = .02$]. For functional health, the mild and moderate groups did not significantly differ from each other in their self-ratings; however, both groups reported significantly worse functional health than the control participants. For vision, the mild and moderate stroke groups did not differ in their self-ratings; however, the mild stroke group reported significantly worse vision than the control participants. The moderate and control groups did not significantly differ in their self-ratings for vision.

Measures and Procedure

A subset of the tasks used in Studies 1 and 2 were used in the present study. Specifically, lexical decision, semantic decision, word recall, story recall, reading speed, and comprehension speed tasks were used in the present study. The same procedure used in the previous two studies was also used in the present study. As in Studies 1 and 2, RT data for both correct and incorrect trials were used. For Occasion 1, there were longer response latencies for incorrect (lexical decision: $M = 1950.70$, $SD = 1573.50$; semantic decision: $M = 4945.81$, $SD = 4302.97$) compared to correct (lexical decision: $M = 1327.49$, $SD = 1165.14$; semantic decision: $M = 3851.05$, $SD = 2250.48$) responses for both lexical decision [$t(2638) = -3.96$, $p < .01$] and semantic decision [$t(2198) = -4.99$, $p < .01$]. Relatively few errors were found across the Persons X Trials data matrix for both RT tasks (lexical decision = 2.16% errors; semantic decision = 5.86% errors). The

average number of errors differed as a function of group for lexical decision [$F(2, 41) = 3.50$, $p = .04$] and semantic decision [$F(2, 41) = 7.50$, $p < .01$]. For the lexical decision task, post hoc comparisons revealed that moderately severe stroke participants had significantly more errors than did controls. For the semantic decision task, post hoc comparisons revealed that moderately severe stroke participants had significantly more errors than both the mild stroke and control participants; the latter two groups did not significantly differ from each other. Similar results were observed for Occasion 2, with one exception: The mild, moderate, and control groups did not differ in the number of errors made for lexical decision [$F(2, 27) = 1.89$, $p = .17$].

Data Preparation

The same data preparation procedure outlined in the previous two studies was used in the present study. For Occasion 1, the number of trials dropped across the entire Persons X Trials data matrix was relatively small (lexical decision = 2.12%; semantic decision = 2.05%) and was unrelated to group [lexical decision: $F(2, 41) = .52$, $p = .60$; semantic decision: $F(2, 41) = .22$, $p = .80$]. Values for the outlier trials were imputed using the same procedure described in the previous two studies. Analyses revealed no trial effect for semantic decision ($b = 2.44$, $p = .36$], and consequently, an individual's mean RT across all remaining trials was used to impute missing outlier trials. A trial effect was found for lexical decision ($b = -2.01$, $p = .01$) indicating that participants responded faster as trials increased. Thus, missing values were imputed by using the mean of nearby points (i.e., a maximum of three points before and three points after the missing value). For Occasion 2, trial effects were found for both tasks and thus missing values were imputed using the mean of nearby points.

Results

The results are presented in five main parts. First, the mild, moderate, and control groups were compared on overall level of performance on the RT and cognitive measures at Occasion 1. Second, the three groups were compared on intraindividual variability on each of the RT tasks at Occasion 1. Third, Pearson product-moment correlations were computed on first-occasion data to determine relationships among (a) measures of intraindividual variability, and (b) measures of intraindividual variability and mean level of performance. Fourth, group differences in longitudinal changes in inconsistency were examined. Fifth, analyses were conducted to determine whether those participants who continued to participate at a second occasion differed from those who did not continue in their levels of inconsistency. For all the analyses, alpha levels of $p \leq .05$ were specified to indicate statistical significance.

Group Differences in Level of Performance at Occasion 1

To compare mild, moderate, and control groups on mean level of performance on each of the RT and cognitive measures, a series of one-way between-subjects ANOVAs, with group (mild, moderate, control) as the between-subjects factor, were performed on each of the variables. Refer to Table 16 for the means and standard deviations. No group differences were found for reading speed [$F(2, 41) = .25$, $p = .78$, $\eta^2 = .001$]. Group differences were found for lexical decision [$F(2, 41) = 9.30$, $p < .001$, $\eta^2 = .31$], semantic decision [$F(2, 41) = 7.79$, $p = .001$, $\eta^2 = .28$], word recall [$F(2, 41) = 3.68$, $p = .03$, $\eta^2 = .15$], story recall [$F(2, 41) = 4.95$, $p = .01$, $\eta^2 = .19$], and comprehension speed [$F(2, 40) = 4.76$, $p = .01$, $\eta^2 = .19$]. Post hoc comparisons revealed that for the lexical and semantic decision tasks, the moderate group took significantly longer to respond compared to the

mild stroke and control groups; the mild and control groups did not significantly differ from each other. Similarly, for the comprehension speed task, post hoc comparisons revealed that the mild and control groups did not significantly differ in their comprehension speed, but the moderate group took significantly longer than both the mild and control groups. Finally, post hoc comparisons revealed that the moderate stroke group recalled fewer words and story propositions relative to both the mild and control groups; the latter two groups did not significantly differ from each other.

Group Differences in Intraindividual Variability at Occasion 1

Intraindividual variability was indexed using ISDs which were calculated using the same procedure outlined in the previous studies. To account for any systematic and group differences, the effects associated with group, trial, age, gender, and all their interactions were partialed from the raw data prior to computing ISDs for Occasion 1. For Occasion 2, the effects associated with occasion, group, trial, age, gender, and all their interactions were partialed from the raw data prior to computing ISDs.

A series of one-way between-subjects ANOVAs, with group (mild, moderate, control) as the between-subjects factor, were computed on ISDs on lexical and semantic decision to determine whether the groups differed in intraindividual variability. The mild, moderate, and control groups were found to differ in intraindividual variability on both lexical decision [$F(2, 41) = 11.57$, $p < .001$, $\eta^2 = .36$] and semantic decision [$F(2, 41) = 14.07$, $p < .001$, $\eta^2 = .41$]. Refer to Figure 2 for a graphical representation. For both RT tasks, post hoc comparisons revealed that the moderate stroke group had significantly larger ISDs compared to the mild stroke and control groups. The mild and control groups did not significantly differ from each other.

Correlational Analyses Between Intraindividual Variability and Cognitive Performance

Pearson product-moment correlations were computed separately for the three groups at the first occasion of measurement in order to examine (a) intercorrelations of intraindividual variability indicators (i.e., ISDs) for the two RT tasks, and (b) relationships among intraindividual variability indicators (i.e., ISDs) for the two RT tasks and mean level of performance on all cognitive tasks.

The intercorrelations between the lexical and semantic decision ISD scores were computed for all three groups. For the mild group the correlation was $r = .67$ ($p = .01$), which indicates that increased variability on semantic decision is related to increased variability on lexical decision. Although the correlations for the moderate ($r = .32$, $p = .59$) and control ($r = .35$, $p = .11$) groups did not reach statistical significance, they were in the expected direction. That is, there is a tendency for increased variability on semantic decision to be associated with increased variability on lexical decision for the moderate and control participants.

In order to compare the mild, moderate, and control groups on the robustness of the relationship between ISD scores, the same procedure outlined in Study 1 was used in the present study. Analyses revealed that the mild ($r = .67$), moderate ($r = .32$), and control ($r = .35$) groups did not significantly differ from each other in the strength of the relationship between lexical and semantic ISDs. Although there were large differences in the mean correlations, these differences did not reach statistical significance since the critical value of $z = 1.65$ was not reached. These correlations indicate that increased variability on one RT task was associated with increased variability on the other RT task.

Correlations between mean level of performance and ISD scores for mild, moderate, and control groups are displayed in Tables 17, 18, and 19, respectively. In general, these data show that increased variability is associated with poorer level of cognitive performance for all three groups, although not all correlations reached statistical significance. This relationship appears to hold for all three groups equally since almost all of the correlations were in the expected direction for the control (100%), mild (100%), and moderate (91.7%) participants. Finally, the magnitude of the correlations in the expected direction was quite high for all three groups and ranged from .08-.78 for the control group, .09-.71 for the mild group, and .10-.86 for the moderate group.

To examine differences between the three groups on the strength of the relationship between ISDs and mean level of performance, the same procedure described in Study 1 was used in the present study, except that there were only three groups of measures: RT tasks, episodic memory, and processing speed. For RT tasks, the groups did not significantly differ in the strength of the relationship between ISDs and RT tasks (mild: mean r = .46; moderate: mean r = .80; control: mean r = .65). Despite large differences between the mean correlations, the critical value of z = 1.65 was not reached. The mean correlations reveal that, for all groups, increased variability is associated with longer RTs. The groups were also similar in the strength of the relationship for episodic memory (mild: mean r = -.38; moderate: mean r = -.55; control: mean r = -.16). Although there were large differences between the mean correlations, the critical value of z = 1.65 was not reached. Mean correlations show that increased variability is associated with poorer episodic memory performance for all three groups. Analyses revealed that the groups did not significantly differ in the strength of the relationship for processing speed

(mild: mean $r = .32$; moderate: mean $r = .37$; control: mean $r = .38$). The mean correlations reveal that increased variability is associated with increased (or, longer) processing speed time for the mild, moderate, and control groups. Overall, no significant group differences in the strength of the relationship were found for any of the measures. However, the mean correlations for all measures were in the expected direction of increased variability being associated with poorer cognitive performance for all three groups.

Longitudinal Changes in Performance

Because only $n = 3$ moderate stroke participants continued to participate at Occasion 2, analyses were conducted to see whether the moderate and mild stroke groups could be collapsed into a single stroke group. Although the groups did not significantly differ on any of the RT or cognitive variables, which was most likely due to small sample size, the moderate and mild stroke groups were not combined because the moderate group's performance was not within one standard deviation of the mild group's performance on all measures except for reading speed. Consequently, all subsequent analyses will compare mild stroke and control groups.

To examine longitudinal changes in mean level of performance, a series of Group (mild, control) x Occasion (first, second) ANOVAs, with occasion as the within-subjects factor and group as the between-subjects factor, were conducted on each of the RT and cognitive measures. No significant differences were found for any of the variables. Refer to Table 20 for the means and standard deviations.

In order to explore longitudinal changes in intraindividual variability, a Group (mild, control) x Occasion (first, second) ANOVA, with occasion as the within-subjects

factor and group as the between-subjects factor, was conducted on lexical decision and semantic decision ISDs. No significant differences were found for both lexical and semantic decision. Refer to Table 21 for the means and standard deviations. Although the moderate stroke group was not included in statistical analyses for the reasons mentioned above, the means for this group will be compared (informally) with the means of the other two groups. The means and standard deviations for the moderate group are also presented in Table 21. For ease of interpretation, refer to Figure 3 for a graphical representation of the lexical and semantic decision ISDs at both occasions of measurement. Close inspection of the means reveals that for lexical decision, there is a trend for the moderate group to have higher ISDs at both occasions relative to the other two groups. Moreover, there is a tendency for the moderate stroke group to have higher ISDs at Occasion 2 compared to Occasion 1. For semantic decision, although the moderate group tends to have higher ISDs than the other two groups at both occasions of measurement, inconsistency shows a tendency to decrease from Occasion 1 to Occasion 2. One final interesting observation is that the mild stroke and healthy controls show a tendency to increase in their inconsistency across occasions for both lexical and semantic decision tasks.

Does Inconsistency Predict Attrition?

To examine whether inconsistency was greater for those who did not continue to participate at Occasion 2, an attrition analysis was conducted comparing the $n = 27$ ($n =$ 13 mild stroke; $n = 14$ control) participants who continued to participate at Occasion 2 with the $n = 12$ ($n = 4$ mild stroke; $n = 8$ control) participants who did not continue to participate at Occasion 2. As previously mentioned, only $n = 3$ moderate stroke

participants continued to participate at the second occasion of measurement and thus this group was not included in any statistical analyses. However, the means for this group will be compared (informally) to those of the mild and control groups. A 2 (group) x 2 (attrition status) ANOVA was conducted on Occasion 1 ISD scores on lexical and semantic decision tasks. No significant differences were found for ISD scores on lexical or semantic decision tasks. Refer to Table 22 for the means and standard deviations for the mild, control, and moderate stroke groups. The table of means reveals that, in general, the dropouts show a tendency toward having more inconsistency on both tasks compared to the returnees; this trend appears to hold for all three groups. However, this difference between returnees and dropouts appears to be more marked for the moderate stroke group relative to the mild stroke and control groups.

Discussion

The present study extends the current body of knowledge regarding intraindividual variability by examining the performance of individuals who have had a mild or moderate stroke, as well as a group of healthy older adults. In addition to exploring the impact stroke severity may have on inconsistency in performance, the present study examined longitudinal changes in inconsistency in these three groups. Analyses revealed group differences in overall mean level of performance on almost all of the RT and cognitive measures at the first occasion of measurement. Specifically, group differences were found for lexical decision, semantic decision, comprehension speed, and word and story recall. For all measures, the moderate stroke group performed more poorly relative to the other two groups, which did not differ from each other. These findings show that, at the mean level of performance, those who suffered a moderate

stroke are more impaired than mild stroke and healthy control participants. Furthermore, mild stroke participants do not show impairments on these measures, since they do not differ from healthy controls.

The three groups were also found to differ in levels of intraindividual variability on both lexical and semantic decision tasks. For both tasks, the moderate stroke group was more variable than both the mild stroke and control groups, which did not differ from each other. These findings suggest that stroke severity does seem to affect performance inconsistency, which is not consistent with other studies which revealed that variability in performance does not vary as a function of severity of injury in TBI patients (Burton et al., 2002; Stuss et al., 1994). Putting the mean level of performance and variability results in the same context shows that these two measures are related to one another. That is, the moderate stroke participants exhibited poorer mean level performance as well as increased variability relative to the mild stroke and control groups. This suggests that poorer mean level of performance is related to greater variability in performance. Moreover, intraindividual variability may be a useful measure to distinguish moderate stroke groups from mild stroke and healthy control groups. Alternatively, the mild stroke and healthy control participants had better mean level performance and less variability in performance compared to the moderate stroke group, suggesting that better mean level of performance is related to less inconsistency in performance. This also suggests that perhaps intraindividual variability is not very useful in distinguishing individuals who have had a mild stroke from healthy controls, at least for more language-based RT tasks such as lexical and semantic decision. Of course, these findings represent a first step in

addressing whether stroke severity affects inconsistency, and future studies using larger sample sizes should be conducted before any firm conclusions can be drawn.

The results of the correlational analyses revealed the same pattern of findings as observed in Studies 1 and 2. Specifically, these correlations showed that greater variability on RT tasks is associated with poorer mean level performance on that same task, as well as on the other RT and cognitive tasks. This pattern was observed for all three groups. This finding is in line with those of other studies (e.g., Hultsch et al., 2000; Hultsch et al., 2002). It was expected that there may be differences between the groups in the strength of the relationship between variability and cognitive performance, however no group differences were found. Taken together, these correlational results indicate that intraindividual variability on a given RT task is associated with an individual's overall mean level of performance on that task as well as on other RT and cognitive tasks, for all three groups. Moreover, the correlation between the ISDs on the lexical and semantic decision tasks revealed that there is a tendency for those who are more variable on one of the tasks to also be more variable on the other task. Once again, this pattern held for the mild, moderate, and healthy control groups. This finding is consistent with previous studies (e.g., Fuentes et al., 2001; Hultsch et al., 2000) and suggests that intraindividual variability may be a stable characteristic in individuals. Although not directly addressed in previous studies, one might predict that the mild, moderate, and healthy control groups would all show stability in variability since intraindividual variability appears to be a stable characteristic in individuals. However, it might be predicted that the strength or magnitude of the correlation between variability across tasks may increase with increasing stroke severity. That is, the moderate stroke group may have the strongest

association because such participants would be expected to show more inconsistency across tasks compared to mild stroke and control groups.

Although the mild stroke and control groups did not significantly differ in the mean level of performance or in inconsistency over time, interesting trends emerged when these two groups were informally compared to the moderate stroke group. These comparisons revealed that there was a tendency for the control group to have increased intraindividual variability on both lexical and semantic decision tasks over time, as was expected. This finding replicates the findings of MacDonald et al. (2003) who found greater intraindividual variability over time in a sample of healthy older adults. Regarding the mild and moderate stroke groups, it could be argued that inconsistency would decrease over time because of the possibility of recovery of function. This idea is based on evidence that TBI patients with a longer time since injury demonstrated less inconsistency relative to those with a shorter time since injury (Hetherington et al., 1996). However, the study by Hetherington and colleagues (1996) used TBI patients ranging in age from 15 to 60 years, and consequently the effects of aging on the recovery process is unclear. Therefore, it was predicted that intraindividual variability would increase over time for the mild and moderate stroke groups due to the effects of aging (MacDonald et al., 2003), despite the possibility of recovery of function. This was the case for the mild stroke participants who demonstrated a tendency towards increased variability on both tasks over time. The moderate stroke group, however, showed a trend of increased variability for the lexical decision task, but a trend of decreased variability for the semantic decision task. This latter trend may reflect the recovery of function over time in the moderate stroke group. Furthermore, this trend suggests that perhaps the recovery of

consistency in performance may occur if the stroke results in a sufficiently large increase in inconsistency that over time may decrease to a level similar to that of the increasing inconsistency of mild stroke and healthy control participants. It should be reiterated, though, that these are informal observations and further studies using larger sample sizes should be conducted before any firm conclusions are drawn.

The attrition analysis revealed that the dropouts were not significantly more inconsistent in performance than the returnees at the first occasion of measurement, contrary to previous findings (e.g., MacDonald et al., 2003). These null results were most likely due to the insufficient power to detect differences because of the small sample sizes used. In fact, an informal comparison of the means for the three groups revealed a tendency for dropouts to show greater inconsistency on the lexical and semantic decision tasks compared to returnees. This trend appeared for all three groups. Another interesting trend that can be noted in the data is that the difference between dropouts and returnees is larger for the moderate stroke group relative to the other two groups. These trends suggest that inconsistency may be predictive of attrition, and that it may differ for individuals of varying levels of stroke severity. Accordingly, examining inconsistency in dropouts and returnees with varying levels of stroke severity may be a promising area of future research.

General Discussion

The main objective of the present thesis was to examine the relatively unexplored topic of intraindividual variability in stroke participants. This objective was accomplished through a series of three studies. The first study compared mild stroke and control participants on inconsistency in performance as well as level of performance. The major

aim of the second study was to determine whether inconsistency could be differentially associated with damage to either the right or left hemisphere in stroke participants. Accordingly, RHD and LHD participants were compared on their levels of inconsistency in performance and mean level of performance. Finally, a third study was conducted to explore (a) whether inconsistency and mean level of performance vary as a function of stroke severity, and (b) two-occasion differences in inconsistency.

The following key results may be highlighted. Study 1 results indicated that stroke participants had greater inconsistency compared to healthy controls (at least on a choice reaction time task), which is in line with previous studies demonstrating that neurologically-impaired adults show greater inconsistency relative to healthy adults (e.g., Hultsch et al., 2000). It was revealed in Study 3 that inconsistency in stroke participants varies as a function of severity, but not lesion laterality as revealed in Study 2. The results of Study 3 are particularly interesting because inconsistency was not found to differ in TBI patients with varying levels of severity of injury (i.e., Burton et al., 2002; Stuss et al., 1994). It is not entirely clear why stroke severity, but not TBI severity, affects consistency in performance. One possibility is that this difference may be due to age differences in the participants used. In the present thesis, older adults ranging in age from 63 to 83 years were used. However, relatively younger participants ranging in age from 17 to 57 years and 18 to 50 years were used in the Stuss et al. (1994) and Burton et al. (2002) studies, respectively. Since relatively younger TBI patients were used in these studies, there were no negative effects of aging on variability in performance. In contrast, the relatively older stroke participants used in the present thesis had the effects of neurological compromise (due to stroke) in addition to the effects of aging negatively

impacting performance. Therefore, age differences may account for the discrepancy in findings between TBI and stroke participants. Another possibility is that there may be differences in the scale of severity used for the TBI and stroke participants. The TBI studies used standard criteria (e.g., the Glasgow Coma scale) to determine severity, and the study by Stuss et al. (1994) reported that all of the patients had been hospitalized as a result of the head injury. In contrast, the present thesis used participants who had self-reported a stroke and the severity of their stroke. In addition, all participants in this thesis reported being in relatively good health. This seems to suggest that the TBI patients may have been more severely impaired than the stroke participants. If this is the case, then one might expect such severely impaired patients to have more consistently low performance as opposed to fluctuating performance, which may account for finding no association between TBI severity and inconsistency.

Taken together, the results of Studies 1 and 3 provide further evidence to support the CNS-neural-noise hypothesis that intraindividual variability at the behavioral level may be an indicator of neurological integrity. With some exceptions, stroke participants with presumed compromised neurological functioning demonstrated more inconsistency than neurologically intact healthy controls. In particular, in Study 3 the moderate stroke group showed greater inconsistency compared to the mild and control groups. Theoretically, individuals with compromised neurological functioning have more random errors or neural noise interfering with the transmission of signals to the CNS. This random interference can affect the clarity with which the signals can be detected from moment to moment. According to Li and Lindenberger (1999) this neural noise and random interference can lead to inconsistency in cognitive performance.

The correlational analyses revealed that greater variability on RT tasks is associated with poorer performance (at the overall mean level) on that same task, as well as on other RT and cognitive tasks. This was found in all three studies, and replicates the findings of Hultsch and colleagues (e.g., Hultsch et al., 2000; Hultsch et al., 2002). In general, these correlational results show that variability in RT is associated with overall mean level performance on RT and cognitive tasks. It was also found, in all three studies, that individuals who were more variable on one RT task were also more variable on another RT task. Thus, it appears that some individuals are consistently more variable in their performance than others. Such findings are consistent with previous research (e.g., Fuentes et al., 2001; Hultsch et al., 2000), and strongly suggest that intraindividual variability is a stable characteristic of individuals.

Because greater intraindividual variability is associated with poorer overall mean level of RT and cognitive performance, it seems that these two measures (i.e., intraindividual variability and mean level of performance) are both good indicators of an individual's general performance. If this is the case, then this raises the question of why would one use the measure of intraindividual variability at all, especially since mean level of performance is a much easier measure to estimate than is intraindividual variability? Examining intraindividual variability is important for the following reasons. First, the measure of intraindividual variability provides an estimate of how variable or inconsistent an individual's performance is. Knowing the extent to which an individual's performance fluctuates is useful because fluctuating performance can have implications in the clinical assessment of an individual or even in an experimental testing situation. A second, and related, reason to examine intraindividual variability is because fluctuating

performance is problematic if only one occasion of measurement is obtained. Consequently, there would not be an accurate picture of an individual's performance. For instance, if only one measurement is taken to characterize an individual's functioning, this may not be valid because on that one occasion the individual may perform better than they usually do, worse than they usually do, or at a level at which they usually perform. However, because performance is known to fluctuate one would not be certain whether the one measurement obtained is representative of the individual's true performance. Accordingly, obtaining performance over short intervals (e.g., trials, days, weeks) may give a more accurate picture of an individual's performance as opposed to just relying on one measurement. Reaction time tasks (such as the ones used in this thesis) are a relatively quick, easy, and convenient way to obtain an individual's performance over a number of trials.

Although inconsistency or fluctuating performance has been portrayed as a relatively problematic characteristic in individuals, there are some cases in which inconsistency may actually be a positive characteristic which may promote or contribute to cognitive growth and development. For example, strategy learning in children is one domain in which there could conceivably be greater intraindividual variability in performance when children are first testing out various strategies to solve a problem. This variability in strategy learning may be beneficial because it leads children to eventually learn which strategies work best in different situations. The benefits of inconsistency are not limited to the beginning of the lifespan, but rather can also be applied to older individuals. Although an older adult may, for example, have a deficit in episodic memory, he or she may try various compensatory strategies to try to deal with or even

improve their failing memory. The older adult may show variability or inconsistency when first trying out various compensatory strategies, but ultimately this inconsistency in behavior may lead to cognitive growth and development in terms of the gain of a new compensatory strategy.

The longitudinal analysis in Study 3 represents the first attempt to examine inconsistency in stroke participants over time. In general, the data revealed a tendency for inconsistency to increase over time for the mild, moderate, and control groups. This trend is consistent with the findings of MacDonald et al. (2003), who demonstrated that inconsistency in performance increases over time in healthy older adults. It would be interesting, however, to examine changes in inconsistency in stroke patients over a longer period of time. Previous findings (e.g., Hetherington et al., 1996) suggest that inconsistency decreases over time for relatively younger adults (i.e., 15 to 60 years), reflecting the recovery of function. In contrast, preliminary findings (i.e., MacDonald et al., 2003) suggest that inconsistency increases with advancing age for healthy older adults. Given these findings, the trajectory of the recovery of function in older adults who have endured a stroke is not clear. Therefore, examining longitudinal changes in inconsistency in stroke patients is especially important because it would help to uncover the recovery process for aging stroke patients. In addition, there was a tendency for those who dropped out of the study after the first occasion of measurement to show greater variability relative to those who continued to participate. This informal observation provides preliminary evidence that intraindividual variability may be able to predict attrition in older adults.

A number of limitations of the present thesis should be discussed. First, not only was the incidence of stroke self-reported by participants, but the severity of the stroke was also self-reported. Future studies using stroke patients should confirm both the stroke and stroke severity using MRI or CT scans rather than relying on subjective self-report measures. Second, no MMSE scores or data about multiple strokes were available for the longitudinal study. This could have presented a problem because the possibility that some participants had dementia or cognitive impairments cannot be ruled out. Furthermore, since information about multiple strokes was not available, this also poses a potential problem because this would have certainly affected performance. Third, small sample sizes were used in the present thesis; future studies should use larger sample sizes. Finally, stroke participants used in the present thesis had varying times since stroke. Therefore, the stroke participants were at different points in the recovery process. To uncover the rate of recovery in older adults who have had a stroke, an interesting future study could be conducted in which patients who have endured a stroke at the same time are followed longitudinally. Not only would such a study provide valuable information about the trajectory of recovery in this population, but it would also provide the opportunity to explore patient characteristics associated with faster and slower rates of recovery. Clearly, this knowledge could have implications for rehabilitation efforts with older adults who have had a stroke.

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Table 1

Means and Standard Deviations of RT and Cognitive Performance as a Function of Group

Measure	Group	
	Stroke	Control
Reaction Time		
SRT	339.79 (61.91)	348.96 (63.89)
CRT	874.31 (146.04)	888.93 (121.13)
Lexical	1175.99 (282.25)	1192.79 (302.40)
Semantic	4026.66 (956.70)	3828.10 (961.80)
Cognitive		
Word Recall	15.70 (4.94)	14.63 (4.84)
Story Recall	.34 (.09)	.34 (.10)
Comprehension Speed	25956.10 (9051.40)	27831.04 (10074.05)
Reading Speed	924.95 (279.78)	1068.05 (386.99)
Perceptual Speed	47.32 (11.11)	45.73 (9.85)

Note. SRT = simple reaction time; CRT = choice reaction time.

Table 2

Means and Standard Deviations of Perfect and Gist Characters Produced as a Function of Trial for Stroke and Control Participants

	Trial				
Measure	1	2	3	4	5
Perfect	2.80 (2.90)†	2.43 (2.33)	2.22 (2.28)	2.27 (2.27)*	1.69 (1.53)*†
Gist	27.79 (6.07)*†	29.79 (6.84)*	30.49 (6.88)	30.96 (6.69)	31.22 (6.48)†

Note. $p < .01$. Means in a row followed by the same subscript differ at $p < .05$.

Table 3

Means and Standard Deviations of RTs as a Function of Block for Stroke and Control Participants

RT Task	Block		
	First	Second	Third
SRT			
Overall	358.08 (73.53)*	334.23 (66.93)*†	351.83 (74.69)†
Stroke	358.99 (74.51)	327.00 (64.77)	350.67 (74.21)
Control	357.17 (74.20)	341.46 (69.69)	352.98 (76.83)
CRT			
Overall	807.70 (169.10)*†	923.85 (149.95)*	922.49 (159.08)†
Stroke	774.52 (154.29)	918.82 (172.82)	925.80 (184.27)
Control	840.88 (179.95)	928.88 (126.77)	919.18 (133.37)
Lexical Decision			
Overall	1400.15 (363.42)*‡	1174.24 (323.79)*†	1119.49 (279.94)†‡
Stroke	1433.45 (413.80)	1170.45 (313.41)	1078.89 (246.28)
Control	1366.84 (310.81)	1178.03 (340.86)	1160.10 (310.15)
Semantic Decision			
Overall	4129.84 (1026.87)*‡	3947.50 (971.53)*†	3766.59 (1033.49)†‡
Stroke	4303.56 (1025.70)	4056.12 (1016.27)	3813.84 (1063.09)
Control	3956.12 (1020.64)	3838.87 (934.42)	3719.33 (1024.65)

Note. RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Means in a row followed by the same subscript differ at $p < .05$.

Table 4

Intercorrelations Between Measures of Intraindividual Variability (ISDs) on RT Tasks for Stroke Participants

	RT Task			
RT Task	SRT	CRT	Lexical Decision	Semantic Decision
SRT	--			
CRT	.55**	--		
Lexical Decision	-.02	-.06	--	
Semantic Decision	.19	.50*	.48*	--

Note. * $p < .05$; ** $p < .01$; RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Table 5

Intercorrelations Between Measures of Intraindividual Variability (ISDs) on RT Tasks for Control Participants

	RT Task			
RT Task	SRT	CRT	Lexical Decision	Semantic Decision
SRT	--			
CRT	.39	--		
Lexical Decision	-.08	.15	--	
Semantic Decision	-.11	.28	.60**	--

Note. ** $p < .01$; RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Table 6

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for Stroke Participants

	Variability (ISDs)			
Mean Level of Performance	SRT	CRT	Lexical Decision	Semantic Decision
SRT	.12	.18	.05	-.07
CRT	.24	.42*	.27	.29
Lexical Decision	-.08	-.19	.85**	.39
Semantic Decision	.16	.40	.68**	.84**
Word Recall	-.08	-.48*	-.06	-.42*
Story Recall	-.22	-.43*	-.22	-.54**
Comprehension Speed	.07	.33	.65**	.46*
Reading Speed	.04	.37	.40	.51*
Perceptual Speed	.11	-.39	-.38	-.38
Copying Speed – word				
Perfect	-.29	-.26	-.05	-.02
Gist	.01	.27	-.48*	-.45*
Copying Speed – h				
Perfect	-.15	-.50*	-.11	-.17
Gist	.27	-.28	-.33	-.22

Note. * $p < .05$; ** $p < .01$; SRT = simple reaction time; CRT = choice reaction time. Gist = Perfect + Gist.

Table 7

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for Control Participants

	Variability (ISDs)			
Mean Level of Performance	SRT	CRT	Lexical Decision	Semantic Decision
SRT	.20	.24	-.01	.04
CRT	-.19	.06	.31	.35
Lexical Decision	.06	.17	.75**	.51*
Semantic Decision	-.20	.14	.62**	.83**
Word Recall	-.01	-.56**	-.52*	-.48*
Story Recall	.34	-.24	-.49*	-.49*
Comprehension Speed	-.27	.16	.56**	.42*
Reading Speed	-.26	-.02	.50*	.35
Perceptual Speed	-.17	-.19	-.30	-.07
Copying Speed – word				
Perfect	.41	-.11	-.25	-.07
Gist	.06	-.16	-.29	-.03
Copying Speed - h				
Perfect	.30	.12	.04	-.21
Gist	-.08	-.01	.01	.13

Note. * $p < .05$; ** $p < .01$; SRT = simple reaction time; CRT = choice reaction time. Gist = Perfect + Gist.

Table 8

Means and Standard Deviations of RT and Cognitive Performance as a Function of Group

Measure	Group	
	RHD	LHD
Reaction Time		
SRT	335.38 (81.75)	355.20 (73.66)
CRT	878.54 (124.44)	815.88 (217.06)
Lexical	1254.10 (358.67)	1065.39 (223.12)
Semantic	3828.32 (1032.87)	4113.25 (666.33)
Cognitive		
Word Recall	16.95 (4.38)	12.13 (3.15)
Story Recall	.36 (.09)	.30 (.01)
Comprehension Speed	27547.27 (9994.92)	25022.70 (8593.05)
Reading Speed	890.10 (288.21)	998.25 (313.66)
Perceptual Speed	46.60 (14.61)	42.75 (6.02)

Note. SRT = simple reaction time; CRT = choice reaction time.

Table 9

Means and Standard Deviations of RTs as a Function of Block for RHD and LHD Participants

RT Task	Block		
	First	Second	Third
SRT			
Overall	358.28 (90.49)	329.91 (81.52)	359.26 (86.57)
RHD	347.42 (96.74)	321.45 (78.02)	354.34 (94.79)
LHD	385.45 (77.63)	351.08 (98.50)	371.57 (72.36)
CRT			
Overall	763.78 (161.54)*‡	890.46 (176.09)*†	911.81 (186.08)†‡
RHD	784.49 (135.87)	911.28 (148.40)	928.55 (166.42)
LHD	712.03 (229.56)	838.40 (251.47)	869.98 (252.38)
Lexical Decision			
Overall	1453.22 (459.20)*‡	1175.42 (360.18)*†	1108.55 (275.79)†‡
RHD	1539.26 (484.87)	1247.98 (393.03)	1127.05 (310.67)
LHD	1238.12 (349.37)	994.03 (193.21)	1062.30 (189.86)
Semantic Decision			
Overall	4120.04 (1020.57)*‡	3900.31 (994.32)*†	3653.19 (845.81)†‡
RHD	4048.80 (1130.98)	3774.62 (1096.04)	3563.68 (898.16)
LHD	4298.14 (785.39)	4214.54 (704.27)	3876.95 (765.83)

Note. RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Means in a row followed by the same subscript differ at $p < .05$.

Table 10

Intercorrelations Between Measures of Intraindividual Variability (ISDs) on RT Tasks for RHD Participants

	RT Task			
RT Task	SRT	CRT	Lexical Decision	Semantic Decision
SRT	--			
CRT	.47	--		
Lexical Decision	-.16	-.34	--	
Semantic Decision	-.01	.34	.57	--

Note. RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Table 11

Intercorrelations Between Measures of Intraindividual Variability (ISDs) on RT Tasks for LHD Participants

	RT Task			
RT Task	SRT	CRT	Lexical Decision	Semantic Decision
SRT	--			
CRT	.50	--		
Lexical Decision	.63	-.34	--	
Semantic Decision	.19	.16	.25	--

Note. RT = reaction time; SRT = simple reaction time; CRT = choice reaction time.

Table 12

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for RHD Participants

	Variability (ISDs)			
Mean Level of Performance	SRT	CRT	Lexical Decision	Semantic Decision
SRT	.29	.33	.14	.16
CRT	.50	.29	.32	.71*
Lexical Decision	-.06	-.22	.90**	.70*
Semantic Decision	-.11	-.01	.79**	.84**
Word Recall	.09	-.31	-.36	-.23
Story Recall	-.02	-.48	-.40	-.80**
Comprehension Speed	-.09	.07	.77**	.70*
Reading Speed	-.17	-.04	.32	.34
Perceptual Speed	.12	-.41	-.34	-.50
Copying Speed – word				
Perfect	-.27	-.16	-.55	-.19
Gist	-.10	-.27	-.47	-.53
Copying Speed - h				
Perfect	-.60	-.57	-.19	-.29
Gist	.28	-.31	-.41	-.73*

Note. * $p < .05$; ** $p < .01$; SRT = simple reaction time; CRT = choice reaction time. Gist = Perfect + Gist.

Table 13

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for LHD Participants

	Variability (ISDs)			
Mean Level of Performance	SRT	CRT	Lexical Decision	Semantic Decision
SRT	-.26	.23	-.65	-.87
CRT	-.89	-.06	-.90	-.13
Lexical Decision	.63	-.20	.75	-.42
Semantic Decision	.68	.86	.04	.58
Word Recall	.57	-.26	.75	-.44
Story Recall	.91	.10	.89	.19
Comprehension Speed	.44	.83	-.36	-.42
Reading Speed	.42	.78	-.12	.74
Perceptual Speed	-.82	-.81	-.10	.16
Copying Speed – word				
Perfect	.46	-.47	.97*	.39
Gist	-.55	.06	-.49	.65
Copying Speed - h				
Perfect	.39	-.48	.74	-.47
Gist	-.25	-.56	.38	.73

Note. * $p < .05$; SRT = simple reaction time; CRT = choice reaction time. Gist = Perfect + Gist.

Table 14

Sample Demographics and Descriptive Characteristics for Control, Mild, and Moderate Participants at Occasion 1

Measure	Group		
	Control	Mild	Moderate
n	22	17	5
Age (years)	72.73 (6.39)	73.12 (6.16)	71.40 (7.70)
Gender (F:M)	17:5	13:4	4:1
Education (years)	13.64 (2.22)	13.24 (3.17)	13.80 (1.30)
Subjective Health	.59 (.45)	.94 (.83)	1.30 (.84)
Functional Health	.41 (.65)†	.78 (.75)*	1.88 (1.42)*†
Hearing	.95 (.72)	.94 (.75)	1.20 (1.30)
Vision	1.14 (.77)	1.18 (.73)	1.20 (.84)

Note. Means in a row followed by the same subscript differ at $p < .05$.

Table 15

Sample Demographics and Descriptive Characteristics for Control, Mild, and Moderate Participants at Occasion 2

Measure	Group		
	Control	Mild	Moderate
n	14	13	3
Age (years)	76.79 (5.31)	76.38 (6.75)	68.33 (2.08)
Gender (F:M)	9:5	9:4	2:1
Education (years)	14.93 (2.20)	13.46 (3.89)	13.67 (2.08)
Subjective Health	.43 (.47)	1.04 (.78)	.83 (.76)
Functional Health	.23 (.28)*†	1.12 (.77)†	.88 (1.02)*
Hearing	.69 (.63)	1.31 (.75)	1.00 (1.00)
Vision	.57 (.51)*	1.15 (.38)*	1.00 (1.00)

Note. Means in a row followed by the same subscript differ at $p < .05$.

Table 16

Means and Standard Deviations of RT and Cognitive Performance as a Function of Group

Measure	Group		
	Control	Mild	Moderate
Reaction Time			
Lexical Decision	1110.17†	1155.32*	2196.82*†
	(281.01)	(220.71)	(1476.93)
Semantic Decision	3462.04†	3536.74*	5782.33*†
	(828.54)	(794.91)	(3028.01)
Cognitive			
Word Recall	16.57†	17.85*	11.90*†
	(4.54)	(4.52)	(.82)
Story Recall	.34†	.30*	.20*†
	(.10)	(.07)	(.08)
Comprehension Speed	25839.61†	26510.48*	47149.35*†
	(11060.31)	(11262.75)	(26799.51)
Reading Speed	1052.86	1104.94	1171.40
	(322.00)	(404.86)	(423.51)

Note. Means in a row followed by the same subscript differ at $p < .05$.

Table 17

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for Mild Stroke Participants

	Variability	
Mean Level of Performance	Lexical Decision	Semantic Decision
Lexical Decision	.71**	.36
Semantic Decision	.22	.46
Word Recall	-.23	-.56*
Story Recall	-.23	-.46
Comprehension Speed	.30	.46
Reading Speed	.09	.39

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

Table 18

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for Moderate Stroke Participants

	Variability	
Mean Level of Performance	Lexical Decision	Semantic Decision
Lexical Decision	.79	.82
Semantic Decision	.73	.86
Word Recall	-.56	.10
Story Recall	-.83	-.63
Comprehension Speed	.53	.22
Reading Speed	.27	.46

Table 19

Intercorrelations Between Mean Level of Performance and Intraindividual Variability (ISDs) for Control Participants

	Variability	
Mean Level of Performance	Lexical Decision	Semantic Decision
Lexical Decision	.77**	.35
Semantic Decision	.60**	.78**
Word Recall	-.11	-.20
Story Recall	-.08	-.26
Comprehension Speed	.43*	.35
Reading Speed	.32	.42

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

Table 20

Means and Standard Deviations of RT and Cognitive Performance as a Function of Occasion for Mild Stroke and Control Participants

Measure	Occasion 1	Occasion 2
Lexical Decision		
Mild	1161.25 (235.63)	1171.95 (321.92)
Control	1119.12 (252.47)	1096.92 (184.98)
Semantic Decision		
Mild	3475.82 (745.02)	3707.33 (958.92)
Control	3406.06 (545.62)	3497.13 (656.54)
Word Recall		
Mild	17.31 (5.00)	17.46 (4.26)
Control	16.54 (4.04)	15.79 (4.54)
Story Recall		
Mild	.29 (.06)	.29 (.11)
Control	.35 (.11)	.32 (.11)
Comprehension Speed		
Mild	25700.41 (12486.36)	27162.24 (14777.50)
Control	24542.16 (9555.88)	23820.54 (8905.51)
Reading Speed		
Mild	1202.67 (420.86)	1126.37 (397.11)
Control	1029.14 (284.72)	919.93 (190.00)

Table 21

Means and Standard Deviations of Intraindividual Standard Deviations (ISDs) as a Function of Occasion for Control, Mild, and Moderate Participants

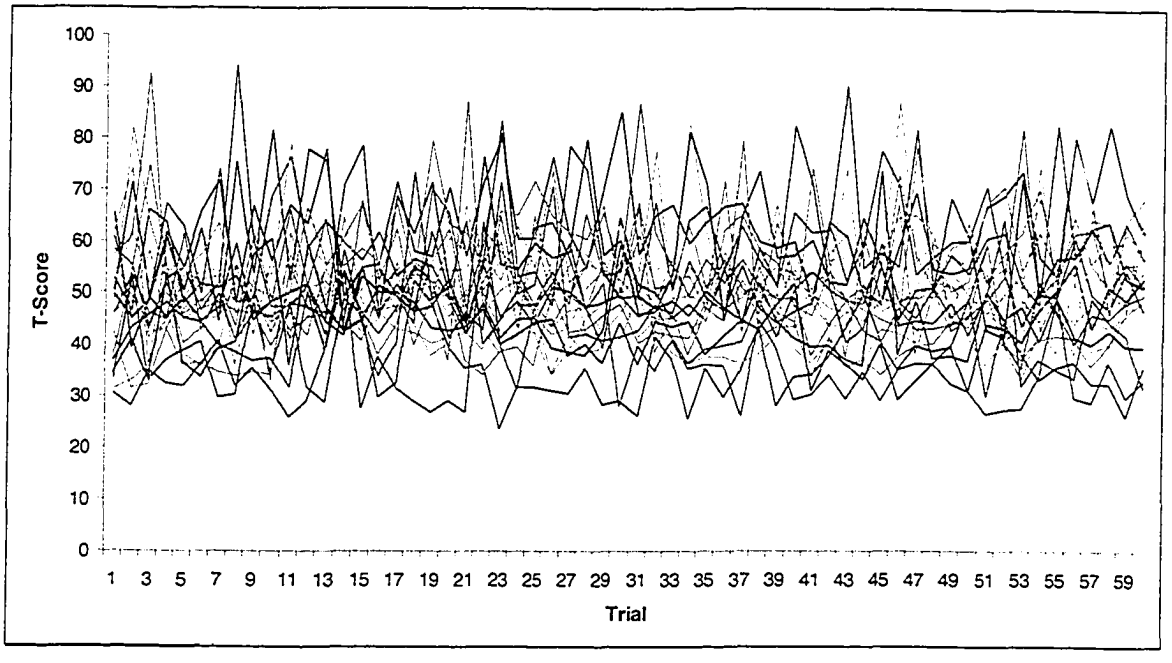
ISDs	Occasion 1	Occasion 2
Lexical Decision		
Control	6.92 (1.81)	7.00 (1.87)
Mild	7.74 (2.75)	8.59 (3.18)
Moderate	9.01 (4.81)	12.55 (5.79)
Semantic Decision		
Control	7.54 (1.35)	7.52 (1.45)
Mild	7.58 (2.28)	8.61 (2.20)
Moderate	11.21 (3.41)	9.95 (3.64)

Table 22

Differences in Inconsistency as a Function of Attrition Status and Group at Occasion 1

	Group		
Measure	Control	Mild	Moderate
Returnees (*n*)	14	13	3
Dropouts (*n*)	8	4	2
Lexical Decision			
Returnees	5.51 (1.53)	5.87 (2.00)	10.78 (7.07)
Dropouts	5.99 (2.00)	5.46 (1.80)	13.43 (8.26)
Semantic Decision			
Returnees	6.67 (1.23)	6.19 (1.83)	9.79 (2.84)
Dropouts	6.97 (1.87)	6.97 (.85)	14.65 (6.22)

(a)



(b)

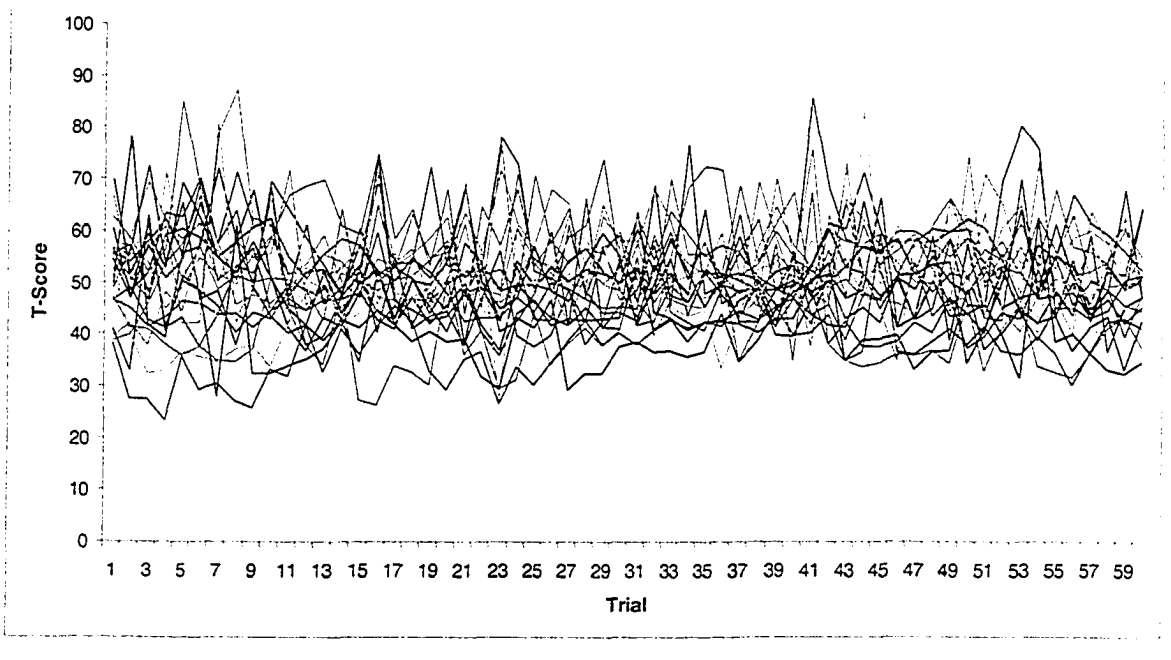


Figure 1. Choice reaction time residual latency *T* scores by trial (after partialing out the effects of group and trial) for (a) each stroke participant, and (b) each control participant.

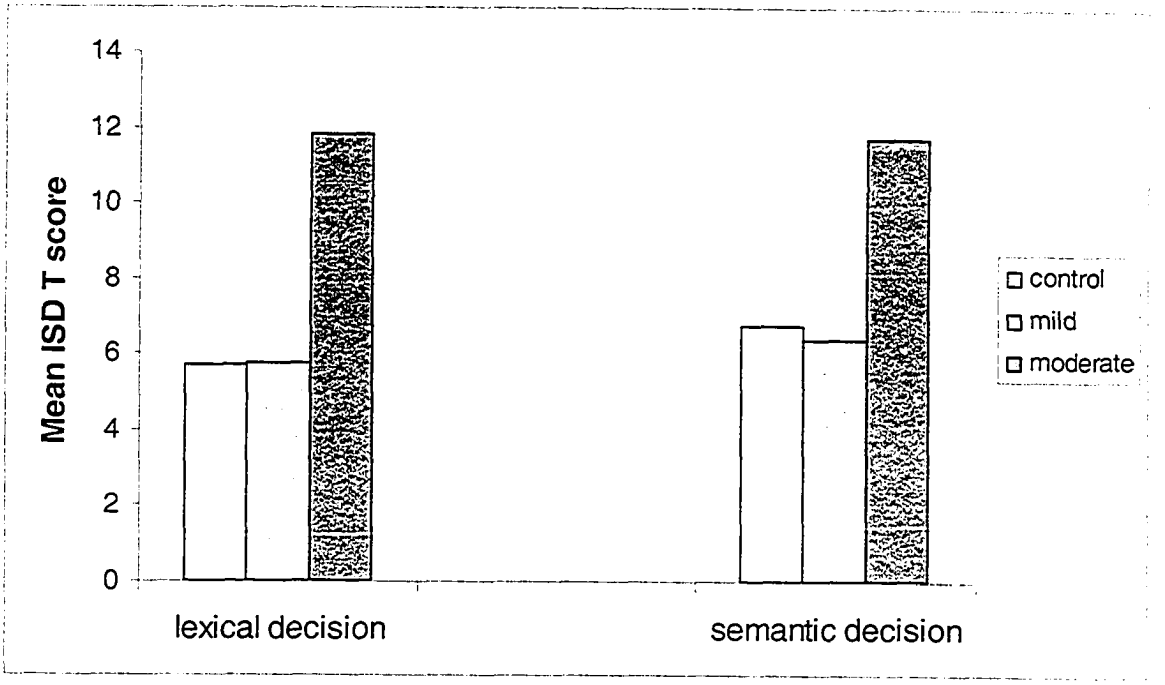


Figure 2. Group differences in intraindividual standard deviations (ISDs) for lexical and semantic decision tasks at Occasion 1.

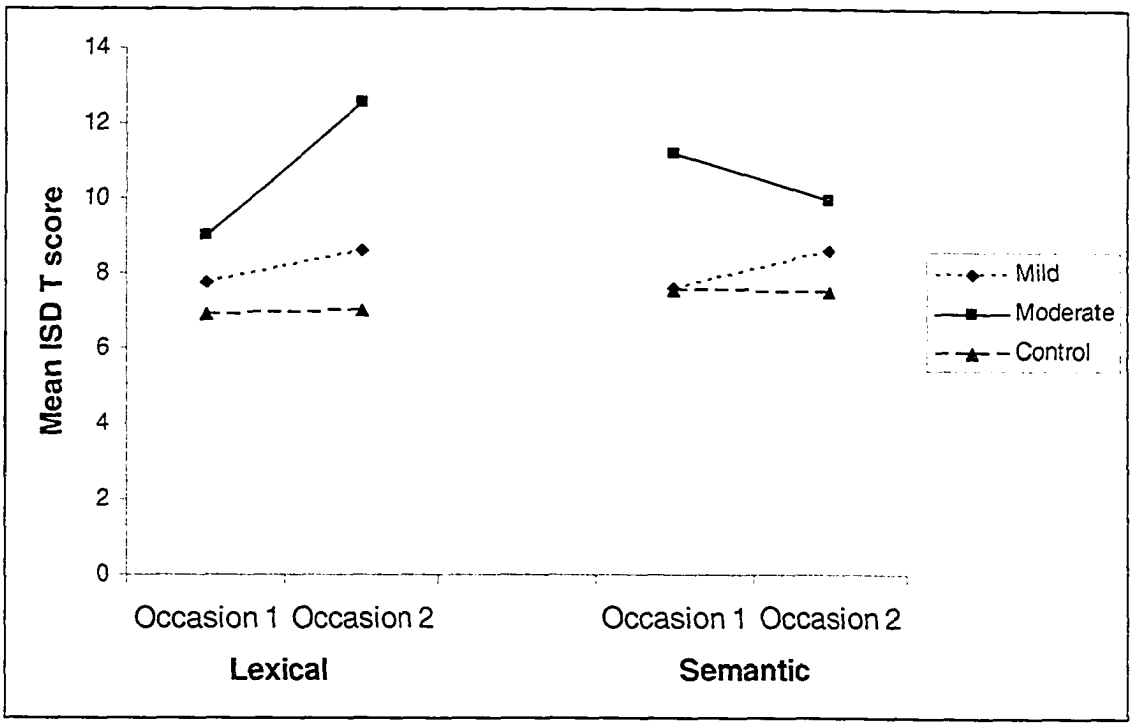


Figure 3. Group differences in intraindividual standard deviations (ISDs) for lexical and semantic decision tasks at Occasions 1 and 2.