

Chronic Fatigue Syndrome:
Intraindividual Variability in Cognitive Functioning

by

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ABSTRACT

Studies of cognitive performance among persons with chronic fatigue syndrome (CFS) have yielded largely inconsistent results. The present study sought to contribute to findings in this area by examining intraindividual variability as well as level of performance in cognitive functioning. A battery of cognitive measures was administered to 14 CFS patients and 16 healthy individuals on 10 weekly occasions. Analyses comparing the two groups in terms of level of performance as defined by latency and accuracy scores revealed that the CFS patients were slower in their reaction speeds than healthy persons. Comparing the groups with respect to intraindividual variability (as measured by intraindividual standard deviations and coefficients of variation) revealed greater intraindividual variability within the CFS group, although the results varied by task and time frame used. Intraindividual variability was found to be fairly stable across time, and consistent across tasks on each testing occasion. The present findings support the proposition that intraindividual variability is a meaningful correlate of cognitive performance in CFS patients.

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Introduction

The present study addressed the topic of intraindividual variability in cognitive functioning among persons with chronic fatigue syndrome (CFS). In order to familiarize the reader with the topic, this paper begins with a review of relevant background information. The first issue addressed is the nature of CFS. Research findings concerning physical and psychological components are presented to provide a broad overview of this condition.

Next, research on the topic of cognitive functioning in CFS is reviewed. Studies in this area are relatively recent; few date back further than the late 1980s. The reader will note that cognitive functioning is an area worthy of study with CFS patients for two main reasons: (1) subjective reports by CFS patients document considerable difficulties in areas such as memory and attention; (2) research findings are fairly inconsistent but do reveal some patterns of cognitive difficulties. The emergence of some trends in research findings suggests that further exploration and clarification of cognitive functioning in CFS patients is warranted.

One of the key goals of the present study was to utilize a novel approach in the study of CFS patients' cognitive abilities, that being the study of intraindividual variability. Intraindividual variability in cognitive performance is a relatively unexplored topic within psychological research, and its study requires a theoretical framework and research methodology that differ considerably from traditional investigations of cognitive functioning. A brief overview and background of the concept of intraindividual variability is provided for the reader, along with an explanation of how a focus on this type of variability differs from mainstream cognitive performance research.

Studies that have looked at intraindividual variability in cognitive functioning among persons with various health problems are reviewed. Although there are few such studies, there is a growing body of evidence supporting the idea that greater intraindividual variability occurs among persons experiencing neurological disease or injury. These findings are relevant to the study of CFS as neurophysiological abnormalities are thought to play a role in the development and/or maintenance of the disorder.

A related area of study concerns intraindividual variability and the aging process. Recent studies have documented greater intraindividual variability in the response speeds of older adults with dementias than in their healthy counterparts, lending support to the possibility that intraindividual variability is associated with compromised neurological functioning. As with the health-related studies, these investigations raise the possibility that CFS patients may also demonstrate greater intraindividual variability than healthy individuals.

In order to address why individual differences in intraindividual variability have been found, two major types of potential causes of intraindividual variability in cognitive performance are presented. One set of explanations focuses on potential neurological causes. The other category of explanations emphasizes internal and external factors that are not solely determined by neurological functioning such as pain and mood states.

After presenting a theoretical background and reviewing pertinent research findings, the research rationale for the present study is outlined. Elements of research on intraindividual variability and cognitive functioning in CFS are synthesized to illustrate why the intraindividual variability approach is particularly relevant for the study of

cognitive functioning of CFS patients. Following from previous findings and the current research rationale, specific hypotheses for the present study are provided.

Chronic Fatigue Syndrome: An Overview

Chronic fatigue syndrome (CFS) has been defined as a disorder that is “characterized by severe and disabling fatigue and fatigability, in the absence of a medical diagnosis to account for this and accompanying symptoms” (Ray, Jefferies, & Weir, 1997, p. 405). A case definition of CFS was first published in 1988 to provide objective guidelines for identifying the disorder in the absence of any reliable biological marker. The definition was revised in 1994 (Fukuda et al., 1994; see Appendix A). The basic requirements include ongoing or recurring fatigue accompanied by at least four symptoms of somatic (and possibly cognitive) distress. It is not a particularly unique or homogeneous disorder in terms of presenting symptoms, as many other disorders (e.g., fibromyalgia) share many symptoms with CFS. Prevalence rates based on community samples range from 7.4 cases per 100,000 (Price, North, Wessely, & Fraser, 1992) to 200 per 100,000 (Jason, Fitzgibbon, Taylor, Johnson, & Salina, 1993). The disorder is diagnosed more frequently among women than men (Joyce & Wessely, 1996), but this does not mean that CFS actually occurs more frequently among women, as men are less likely to seek treatment for their symptoms (Richman, Flaherty, & Rospenda, 1994).

Chronic fatigue syndrome is a puzzling disorder because of its unknown etiology. It is a diagnosis given by physicians, but there is considerable debate about whether it represents primarily biological processes or whether it is largely the result of psychological dysfunctions. Sharpe (1996) noted that a medically unexplained disorder such as CFS does not fit neatly within current dualistic classification and diagnostic

schemes that separate mind and body, raising the danger of prejudice by those who consider CFS to be a personal weakness rather than an uncontrollable biological problem. Alternatively, persons with CFS who focus on medical aspects of their problems to the exclusion of psychological aspects often face greater disability, as will be discussed later.

Various disease-based causes of CFS have been proposed, including viral infections. Persons with CFS often cite a viral infection as the trigger for their illness (e.g., Wessely & Powell, 1989). Reports in the mid-1980s pointed to the Epstein-Barr virus as a likely cause of some cases of chronic fatigue, but this explanation is no longer considered valid (Fukuda, 1997). A review of literature examining the connection between viruses and CFS concluded that the evidence supporting a causal link is weak (Hotopf & Wessely, 1994). However, as White (1997) pointed out, establishing the etiology of such a heterogeneous disorder is complex, and some viral infections are linked with subsequent non-CFS fatigue (e.g., White et al., 1995). It is possible that infectious agents may represent only one of several interactive precursors to CFS, including social and psychological factors (see Salit, 1997).

Disruptions in central nervous system functioning are often cited as playing a role in the development or maintenance of CFS. Investigations of neurological functioning in CFS patients have revealed fairly consistent but unclear results. Neuroimaging studies often reveal abnormalities of cerebral white matter, but these abnormalities are not found in all CFS patients and are also found in some healthy persons (see Tiersky, Johnson, Lange, Natelson, & DeLuca, 1997). Neuroendocrine abnormalities have also been identified, particularly low levels of cortisol and heightened serotonin activity (Cleare et

al., 1995). A definitive pattern or marker of neurological dysfunction in CFS patients has not been identified. A recent study found abnormalities in muscle fibre structures in persons with CFS, raising the possibility that peripheral defects occur in at least a subgroup of CFS patients (Pizzigallo, Racciatti, & Vecchiet, 1999).

Understanding the origins of CFS is further complicated by high co-morbidity between CFS and psychological disorders. Depression (Kendell, 1991), and anxiety (Salit, 1997) are particularly common among persons with CFS. In a recent review paper, Sharpe (1996) pointed out that, in persons who were diagnosed with both depression and CFS, the onset of both disorders usually coincided. He also reviewed evidence that the rates of depression among persons with CFS are much higher than those found among persons with other chronic, disabling organic disorders. This raises the possibility that CFS is a misdiagnosed psychiatric illness. However, disorders such as major depression do not account for all of the clinical features observed in CFS patients, despite the high co-morbidity between CFS and psychological disorders (Sharpe, 1996). Also, one third to one half of CFS patients do not meet criteria for any psychiatric disorder (Joyce & Wessely, 1996). Somatization disorder is the most likely candidate for a psychiatric illness that could explain CFS, but few CFS patients meet criteria for this disorder (Johnson, DeLuca, & Natelson, as cited in Salit, 1997).

The role that psychological and purely physiological influences play in the onset, development and maintenance of CFS is unclear, but current evidence suggests both types of factors contribute to CFS at some point. Sharpe, Chalder, Palmer, and Wessely (1997) noted that different types of factors may all play a role in perpetuating CFS. As part of a case example, they suggested that biological factors such as the effects of inactivity, cognitive factors such as a belief in a viral infection, and social factors such as

unemployment may all serve to maintain the disorder. Physical inactivity may directly contribute to increased feelings of fatigue, and social factors may indirectly help to maintain CFS either by providing secondary gains for patients or by creating barriers to recovery (e.g., a decrease in income due to unemployment could limit the treatment options available to a patient).

Psychological Factors

Research concerning the psychological aspects of CFS has only recently started to emerge. Findley, Kerns, Weinberg, and Rosenberg (1998) examined two dimensions of self-efficacy and their relationships with symptom severity, disability and distress. They found that a belief in the ability to function despite CFS was predictive of fewer symptoms. The other dimension of self-efficacy, a belief in the ability to manage symptoms, was related to lower levels of disability and distress.

Although the course of CFS is variable, only a minority of patients experience significant improvements, with the majority experiencing slight improvements, a constant level of disability or increasing difficulties (Bombardier & Buchwald, 1995; Wilson et al., 1994). Illness beliefs play a major role in the course of CFS. Specifically, patients who attribute their problems to an unknown organic cause tend to have worse outcomes than those who acknowledge other possible causes (Heijmans, 1998; Joyce & Wessely, 1996). These patients tend to experience ongoing problems in social functioning as well as physical health. This is a troubling finding because persons with CFS usually attribute their difficulties to organic causes, even when no supporting evidence is present (Sharpe, 1996).

Not all research supports the idea that attributions of organicity are related to poor outcomes. In a treatment study, Deale, Chalder, and Wessely (1998) examined the role

of illness beliefs in the treatment of CFS using cognitive-behavioural and relaxation methods. They found that neither treatment affected illness beliefs. Moreover, illness beliefs were not related to outcomes; persons who believed their problems were due to an organic cause did not fare more poorly than persons with broader causal beliefs. Instead, they found that a belief that exercise should be avoided was related to poorer outcomes. These results are promising because they suggest that CFS patients do not need to alter their convictions of physical causes in order to experience improvement. Considering that many (if not most) CFS patients are strongly opposed to non-physical explanations of CFS (see Wessely, 1997), working with illness beliefs other than those of organic causality may prove to be more viable treatment avenues.

In a study of potential mediators of outcomes, Ray, Jefferies, and Weir (1997) found that, at a one-year follow-up, anxiety and depression were not useful predictors. Illness duration, subjective cognitive difficulty, and number of somatic symptoms were positively correlated with fatigue and functional impairment. Low levels of activity were associated with poorer outcomes only in the presence of an internal locus of control.

A separate issue from long-term outcomes is the short-term fluctuations in functioning that CFS patients experience. There is considerable within-person variability in terms of the magnitude and nature of symptoms that are experienced on a weekly or even daily basis. Jason et al. (1999) conducted a study in which two CFS patients used actigraphs to record their levels of activity for 15 days and then retrospectively reported levels of symptoms. Even over this relatively short time span, noticeable shifts in symptoms occurred along with concomitant changes in activity levels. Data pertaining to psychological factors such as mood and thinking patterns were not collected in this study,

but it would be reasonable to surmise that such factors might vary in accordance with CFS symptoms. For example, an increase in pain might be accompanied by a negative shift in mood.

Cognitive Functioning

A common complaint among persons with CFS is that of diminished cognitive abilities. Self-reports of cognitive problems reflect perceptions of considerable difficulties (Altay et al., 1990; Ray, Phillips, & Weir, 1993). In particular, attention, memory, and concentration abilities are frequently identified as problematic by CFS patients (Altay et al., 1990; DeLuca, Johnson, Beldowicz, & Natelson, 1995). In addition to complaints of actual performance difficulties, CFS patients have also been found to complain that they find mental effort aversive (Wearden & Appleby, 1996).

Neuropsychological testing of CFS patients has produced mixed results. When immediate attention abilities (attention span) are assessed with digit span tasks, some studies fail to find any differences between CFS patients' performance and that of control participants' (DeLuca et al., 1995; Krupp, Sliwinski, Masur, Friedberg, & Coyle, 1994), whereas others find impaired performance among CFS patients (DeLuca, Johnson, & Natelson, 1993; Michiels, Cluydts, & Fischler, 1998). Ray et al. (1993) administered the Stroop Colour Word Test and the Embedded Figures Test, two tasks that require focused attention (i.e., the ability to attend to a stimulus while ignoring distracting information), to CFS patients and controls. Results did not suggest any deficits in focused attention. Similarly, Grafman et al. (1993) found no evidence of impairment among CFS patients with respect to sustained attention. In the Grafman study, participants completed a computerized reaction time task that required them to respond to a target stimulus

presented with distracting stimuli. Control group participants and CFS patients did not differ with respect to accuracy, but response latencies were significantly slower among the CFS group.

Other studies that have included measures of accuracy in cognitive performance have yielded different results. Smith, Behan, Bell, Millar, and Bakheit (1993) administered a computerized vigilance task to CFS patients and healthy adults and found that the CFS group performed more poorly. Michiels et al. (1998) found that there were no differences in accuracy between CFS patients and healthy controls on a choice reaction time task, but CFS patients' accuracy was significantly poorer than the controls' on a sequential reaction time task.

Memory sometimes appears impaired and at other times appears normal. When digit span tasks are regarded as measures of working memory, results are mixed (see above). In their review of the literature, Tiersky et al. (1997) reported that four studies have found evidence of impairment among CFS patients on word list learning tasks, but twice that number of studies found no differences between CFS patients' and controls' performance. The authors also reported that results pertaining to visual memory are inconclusive, with several studies failing to find impairment in nonverbal memory but about half as many finding evidence of significant impairment. Tiersky et al. concluded that recall abilities are largely unaffected among CFS patients, but there may be some difficulties with initial acquisition of information. Learning and recall of verbal information may also be compromised as the level of semantic complexity increases, which may account for conflicting results in studies of paragraph recall.

One area in which results are highly consistent is the assessment of intelligence. Persons with CFS score in the average to high average range, and no evidence of intellectual decline following onset of the illness has been found (Tiersky et al., 1997). Another area in which findings are fairly consistent pertains to reaction times. Both simple and complex reaction time tasks are usually characterized by slower performance among CFS patients than controls (Grafman et al., 1993; Scheffers, Johnson, Grafman, Dale, & Straus, 1992; Marshall, Forstot, Callies, Peterson, & Schenck, 1997; Smith et al., 1993; Smith et al., 1999).

Individuals with CFS also tend to demonstrate less efficient information processing than controls with respect to auditory information. Studies that have involved administering the Paced Auditory Serial Addition Test (PASAT) have uniformly found impaired performance among CFS patients (DeLuca et al., 1993; DeLuca et al., 1995). Johnson, DeLuca, Fiedler, and Natelson (1994) administered both the PASAT and its visual counterpart to CFS patients, multiple sclerosis patients, and controls. They found that CFS patients were significantly more impaired on the PASAT than the visual task, suggesting a marked deficit in the processing of auditory information as compared to visual information. However, as discussed above, results based on digit span tasks have been mixed.

Findings concerning efficiency of processing visual information also point to some degree of impairment among CFS patients. Persons with CFS have demonstrated significantly slower performance than controls on Stroop tasks (Marshall, et al., 1997; Ray et al., 1993) and the Digit Symbol task (Krupp et al., 1994; Michiels et al., 1996). Many studies have failed to find any group differences when the Trail Making Test is

used to assess visual processing speed (e.g., Altay et al., 1990; DeLuca et al., 1995; Krupp et al., 1994), although Michiels et al. (1996) did find slower performance among CFS patients.

It is difficult to generalize across studies in this area but the general consensus in the literature appears to be that, although some studies do produce evidence of cognitive impairment, testing results fall short of reflecting the magnitude of CFS patients' complaints (Johnson, Lange, DeLuca, Korn, & Natelson, 1997; Tiersky et al., 1997; Weardon & Appleby, 1996). Nonetheless, evidence for subtle difficulties exists. In a recent review, two trends in results were identified: (1) CFS patients tend to demonstrate slower performance, either by longer/more variable reaction times or delayed information processing; and (2) results that suggest poorer performance among CFS patients are generally based on more difficult tasks, including those which require high levels of effortful processing (Wearden & Appleby, 1996).

The disparity between CFS patients' perceptions and their actual performance should not be interpreted as a global inability to accurately evaluate cognitive performance. Wearden and Appleby (1997) administered a naturalistic reading task to evaluate recall performance among persons with CFS as well as CFS patients with a comorbid diagnosis of depression. Participants were asked to complete a measure of perceptions of cognitive functioning prior to the task, and this measure revealed that participants' perceptions were unrelated to actual recall performance. In contrast, when participants were asked after completing their reading how well they thought they could recall the material, their predictions were largely accurate and better than those of participants in a control group. Thus, CFS patients seem to be able to use specific

information to accurately evaluate their cognitive functioning even though their general perceptions tend to overestimate impairments.

Several putative explanations have been proposed to account for the wide range of findings related to CFS patients' cognitive functioning and the discrepancies between subjective complaints and objective findings. Many authors have emphasized the heterogeneity of CFS patients, suggesting that there may be subgroups of CFS patients that differ with respect to levels of impairment (Vercoulen et al., 1998). Methodological factors such as failure to use control groups are often underscored when trying to reconcile opposing findings. One obvious methodological limitation of previous studies is that they have employed single-occasion measurement designs. Patients are tested at one point in time, and results are extrapolated to represent functioning at most points in time. An alternative approach would be to sample cognitive abilities at different points in time. Kane, Gantz, and DiPino (1997) proposed that multiple testing occasions may be particularly informative for CFS patients as single-session measurements tend to yield inconclusive results. In discussing possible reasons why their results indicated less cognitive impairment than was subjectively reported by CFS patients, the authors wrote: "...it appears conceivable that levels of fatigue and effort would vary over an extended period of time or over repeated performance demands. An approach which employs repeated measures and is capable of examining the consistency of performance of CFS patients over the course of a day, or several days, may help clarify the nature of cognitive complaints given by CFS patients" (Kane et al., 1997, p. 30).

Intraindividual Variability: An Alternative Perspective

Research on cognitive abilities has tended to follow a traditional approach, which states that cognitive abilities are stable and any short-term fluctuations are due to random or test error. For example, a person's score on an intelligence test may vary by a few points when tested on two occasions, but this variation is thought to be due to the fact that no test is entirely free from measurement error. If a test is perfectly reliable and valid, then it should yield virtually the same score every time it is administered to an individual because the phenomenon being measured does not change. Any minute deviations in scores could be due to transient factors not meaningfully related to performance, such as excessive noise in the testing environment.

Difficulties arise when stability and reliability are erroneously used as interchangeable phenomena. Stability refers to constancy of an attribute, such as intelligence. Attributes that are thought to be highly stable are often referred to as traits, or traitlike, whereas attributes that are subject to considerable change (e.g., mood) are often referred to as state variables. Reliability refers to the ability of an instrument to accurately measure an attribute across time, whether or not the attribute is stable. In other words, a truly reliable instrument is sensitive to change.

When appropriate methods are used, some traitlike variables demonstrate short-term fluctuation (intraindividual variability). Locus of control and work values, two attributes that are generally thought to be highly stable, have been shown to vary on a daily basis (Roberts & Nesselroade, 1986). An attribute may be highly stable over the long term (as is often the case when traitlike attributes are measured at a few, highly separated points in time), or may show only gradual change, but such stable traits can

also fluctuate significantly within a short window of time. Short-term variability is not random error (and thus meaningless); it represents changes in the organism's state (Nesselroade, 1991).

Cognitive abilities have also been found to fluctuate markedly on a short-term basis. In a study by Englund, Ryman, Naitoh and Hodgdon (1985), the effects of physical exertion, lack of sleep, continuous work, and time of day on cognitive performance were examined. Healthy volunteers were tested repeatedly over a 48-hour period during which they were allowed only a three hour nap. Sleep loss and degree of physical activity were related to cognitive performance. Time of day was also related to cognitive performance, above and beyond the effects of physical activity and sleep loss. Hertzog, Dixon and Hultsch (1992) tested text recall in seven older women on a weekly basis for a period of two years. They found significant intraindividual variability in the results of all participants demonstrating that, in an older age group, performance varies significantly even in the absence of undue stressors.

Although intraindividual variability has been given little attention in research on cognitive abilities, the above findings illustrate both that it is a real phenomenon and that single-occasion measurements of cognitive abilities are not entirely accurate. As Staudinger, Marsiske and Baltes (1995, p. 804) note: "A one-time assessment of intellectual functioning, for example, ignores the fact that individuals may score differently on intelligence tests depending on factors like anxiety, fatigue, perceived relevance of the test, and level of baseline performance." Some tests of cognitive abilities are designed to provide a confidence interval that captures the range in which true abilities lie, but many tests provide only a single "true" score. Even when

confidence intervals are available, most test results are interpreted according to the obtained score rather than the likely range of abilities. Furthermore, the magnitude of intraindividual variability that has been detected in some studies suggests that some confidence intervals (e.g., those calculated at the 5% level) may not be liberal enough to reflect true parameters of performance.

A more accurate approach to testing cognitive abilities would be to employ what Nesselroade (1991, p.235) has termed “bursts of measurement”. Conducting repeated measurements over a short period of time highlights the magnitude and direction of intraindividual variability in cognitive performance. Also, this approach allows for the identification of factors that are related to variability, as well as the direction and magnitude of the relationships between covariates and performance. As Nesselroade (1991) has pointed out, the issue of the relationships between covariates and intraindividual variability becomes particularly important when they result in a cyclical pattern of change. When intraindividual variability follows a pattern, even multiple measurements of performance may be misleading if they all occur at the same point in the cycle. For this reason, it is necessary to sample many occasions that do not follow any particular pattern.

A caution to bear in mind when considering the merits of multiple measurements is that systematic effects will influence performance over time. For example, repeatedly administering the same or parallel forms of a test will likely lead to practice effects. For this reason, it is necessary to distinguish between variance due to cumulative exposure to a measure and true variance, or individual variability. This can be done through statistical procedures that separate these two sources of variability in performance.

Intraindividual Variability in Persons with Health Problems

As discussed above, cognitive performance in healthy, non-elderly individuals fluctuates on a short-term basis when stressful conditions (e.g., sleep loss) are instituted. Intraindividual variability also occurs in persons with various health or physical problems. For example, there is a long history within brain injury literature of associating inconsistent performance with brain injuries. Head (as cited in Bleiberg, Garmoe, Halpern, Reeves, & Nadler, 1997) pioneered this line of thinking in the early part of the 20th century with his observations of inconsistent performance in persons with brain injuries. More recently, research has demonstrated that considerable variability can occur both within a single testing session (see Reed, 1998, for a review) and across time. Stuss, Pogue, Buckle, and Bondar (1994) administered a visual reaction time task to a group of individuals with traumatic brain injuries (with varying levels of severity) and a group of healthy controls. The task was given a second time after a one-week interval. When the two groups were compared, participants with brain injuries demonstrated greater intraindividual variability in their reaction time within each occasion. This group also demonstrated greater intraindividual variability than the control group across the one-week interval, although this finding did not apply to all tasks. Hetherington, Stuss, and Finlayson (1996) administered a battery of reaction time tasks to a group of persons who had experienced a traumatic brain injury (TBI) five years ago, another group who had sustained a TBI 10 years ago, and a control group. The battery was given again 7 days after the initial testing occasion. Intraindividual variability was associated with reaction times on each occasion in both TBI groups but not the control group. Bleiberg et al. (1997) administered a cognitive test battery 30 times over 4 days to a TBI group

and a control group. The TBI group demonstrated greater intraindividual variability than the control group, and some participants in the TBI group demonstrated a decline in performance across time, unlike the control group. Finally, Bleiberg, Garmoe, Cederquist, Reeves, and Lux (1993) found that a sedative medication increased the magnitude of intraindividual variability in a person with TBI whereas a stimulant led to a decrease, demonstrating that intraindividual variability in individuals with TBI can vary according to biochemical factors.

Intraindividual variability in CFS patients has not been examined but their cognitive performance has been compared with that of persons with neurological problems. Tiersky, Cicerone, Natelson, and DeLuca (1998) compared the cognitive performance of persons with CFS with individuals who had sustained mild traumatic brain injury (MTBI) and found that, in general, CFS patients' performed better than the MTBI group but not as well as a group of healthy controls. It is possible that this pattern of results could also extend to the magnitude of intraindividual variability, with CFS patients demonstrating less variability than persons with brain injuries but more than healthy individuals. Carbotte, Denburg, Denburg, Nahmias, and Garnett (1993) found that cognitive performance in persons with lupus, a disorder of the central nervous system, varied according to patterns of glucose metabolism within the brain. This suggests that CFS patients, who also experience variable central nervous system functioning, would likely demonstrate fluctuations in cognitive functioning according to variability in central nervous system functioning.

Recent research suggests that persons with CFS are vulnerable to fluctuations in their cognitive performance. Smith et al. (1999) administered a lengthy battery of

cognitive tasks, including measures of reaction time and reasoning ability, to CFS patients and healthy individuals. They found that at the beginning of the testing session CFS patients were slower than healthy persons on reaction time tasks, but this difference increased markedly as the patients' level of fatigue increased over time. The authors suggest that CFS patients may be more sensitive to factors that reduce arousal (e.g., prolonged performance, sleep disturbance) than healthy adults. Based on the results of Smith et al. (1999), it appears that there is a fairly linear relationship between fatigue and cognitive performance within a session for CFS patients. However, fatigue could lead to significant intraindividual variability across testing sessions as well. Persons with CFS could experience significant deviations from their typical performance if tested when they are very fatigued.

Intraindividual Variability in Older Adults

Recent research suggests that intraindividual variability in some cognitive domains increases with age. Shammi, Bosman, and Stuss (1998) tested the cognitive performance of younger and older adults on two occasions a few days apart. They found that older adults demonstrated greater intraindividual variability than the younger participants across occasions, but only on tasks that posed a high level of cognitive demands. Older adults did not demonstrate greater intraindividual variability than younger adults within occasions.

One possible explanation for the positive relationship between age and intraindividual variability is that changes in neurological functioning accompany the aging process. In particular, research involving older adults has provided evidence that the magnitude of intraindividual variability may vary as a function of underlying

neurobiological dysfunction, particularly when such dysfunction is the result of a dementing illness. Knotek, Bayles and Kaszniak (1990) administered a picture naming task twice to three groups: persons with mild or moderate impairment resulting from probable Alzheimer's disease, and healthy controls. Moderately impaired participants demonstrated the greatest degree of inconsistency in responses, followed by mildly impaired persons and then the healthy individuals. Dixon, Hertzog, Friesen and Hultsch (1993) tested ten non-impaired older women and one woman with probable Alzheimer's disease. They completed a story recall task on a weekly basis for ten consecutive weeks. All individuals demonstrated considerable intraindividual variability. The participant with probable Alzheimer's tended to demonstrate weaker performance than the non-impaired participants, but her results occasionally overlapped with others'. Finally, Hultsch, MacDonald, Hunter, Levy-Bencheton, and Strauss (2000) compared the cognitive performance of healthy older adults with two groups of age peers: persons with arthritis and individuals with mild dementia. They found that intraindividual variability in response latencies was greatest among the dementia patients, but arthritis patients did not demonstrate appreciably greater intraindividual variability than the healthy participants.

Intraindividual variability among older adults is related to other factors as well as dementia-related neurocognitive decline. Anstey (1999) administered reaction time tasks to relatively healthy older women and found that intraindividual variability in reaction times was associated with physiological measures (e.g., grip strength), suggesting a positive relationship between central nervous system functioning and intraindividual variability. Li, Aggen, Nesselroade, and Baltes (2000) tested healthy older adults and

found that intraindividual variability in memory functioning was associated with intraindividual variability in sensorimotor functioning. Although the number of studies in this area is small, there is growing evidence that intraindividual variability is predictive of various areas of neurocognitive functioning among older adults.

An important issue to be considered when examining intraindividual variability in any age group is the definition of cognitive performance. Most studies that have assessed intraindividual variability have relied on response times, or latencies, as a marker of cognitive performance (e.g., Anstey, 1999), and have demonstrated an inverse relationship between intraindividual variability and performance. Studies that have used multiple markers of performance have found that relationships between intraindividual variability and performance is dependent on how performance is defined. Hultsch et al. (2000) assessed accuracy of performance in addition to latencies and found that intraindividual variability was more strongly related to latency rather than accuracy (although the direction of the relationships remained the same, with greater intraindividual variability being associated with poorer accuracy as well as longer latencies). Similarly, Li et al. (2000) measured both the number of steps and the time required to complete a walking task, and found a stronger association between intraindividual variability and the number of steps rather than the completion time. CFS patients may also demonstrate relatively weaker or stronger associations between intraindividual variability and performance depending on how performance is defined and measured. Further, there may be particular patterns of intraindividual variability in cognitive performance (e.g., significant intraindividual variability on some types of tasks

but not others) that are unique to CFS and could serve as possible markers of the disorder.

Possible Underlying Cause of Intraindividual Variability

Many hypotheses regarding the causes of intraindividual variability invoke neurological dysfunctions or abnormalities. Reed (1998) developed a model suggesting that cortical pathway lengths (i.e., neural transmission routes involved in executing an action) may vary within individuals over time, leading to intraindividual variability on reaction time tasks. Computational models have been used to argue that intraindividual variability is related to the efficacy of neural transmissions, with diminished catecholaminergic functioning emerging as a precursor of increased cognitive intraindividual variability (Li, Lindenberger, & Frensch, 2000).

Another potential neurological factor related to intraindividual variability is general decline in central nervous system or brain functions. The “common cause” hypothesis maintains that an overall impairment of central nervous system functions results in impaired cognitive functioning. In support of this notion, sensorimotor and physiological measures (e.g., observing the number of steps required to walk in a circle) that are considered indicative of the degree of central nervous system integrity have been found to be strong predictors of levels of cognitive functioning (e.g., Anstey, 1999; Baltes & Lindenberger, 1997; Li et al., 2000) and intraindividual variability in cognitive functioning (Anstey, 1999; Li et al., 2000). Results demonstrating a link between neurological functioning and intraindividual variability underscore the relevance of examining this type of variability in CFS patients as functional impairment in central nervous system functioning is generally regarded as a key feature of CFS.

Findings based on older adults and individuals with traumatic brain injury provide support for the argument that neurological disruptions may be manifested in increased intraindividual variability. However, this does not imply that neurological dysfunctions are the sole cause of heightened intraindividual variability. As demonstrated in the Englund et al. (1985) study, influences such as amount of sleep and physical activity, which are not neurological factors *per se*, are related to cognitive performance. Considering that there are individual differences in the effects of such factors (e.g., some individuals function effectively after four hours of sleep whereas others require eight), it is likely that there are also individual differences with respect to how such influences affect intraindividual variability. For example, short-term sleep pattern disruptions might be associated with marked intraindividual variability in one individual's cognitive performance but might have few noticeable effects on another person's performance. Also, Li et al. (2000) point out that behavioural measures of cognitive performance reflect exogenous as well as internal factors, so that both types of variables play a role in intraindividual variability even if there is a direct connection between neurological functioning and fluctuations in performance.

One variable that could directly determine the relative effects of non-biological influences is health status. Persons with illnesses or somatic problems could be more vulnerable to non-neurological influences either because of an overall decline in resilience or specific effects of their condition. Negative changes in health status could result in fluctuations in levels of pain, mood, and sleep efficiency both over short- and long-term periods of time. Variability in these areas of functioning could result in increased intraindividual variability in cognitive performance. Ongoing research is

currently investigating the relationships between sleep, pain, mood states and intraindividual variability in cognitive functioning (D. F. Hultsch, personal communication, Mar. 28, 2000). Although the magnitude of these relationships remains to be seen, it seems plausible that the relative effects of such influences will be greater for persons with somatic problems who experience greater fluctuations in sleep, mood states, and levels of pain than healthy individuals.

Research Rationale

Wearden and Appleby (1996) noted that although differences between CFS patients' and control group participants' results do not usually reach statistical significance, there tends to be a consistent trend in that CFS patients perform more poorly than controls. They suggest that these minor but consistent differences are probably not due to major brain dysfunctions, although subtle disturbances in a subgroup may exist (e.g., Vercoulen et al, 1998). Instead, Wearden and Appleby attribute the somewhat poorer performance of CFS patients to psychological factors including mood, arousal, motivation, and effort. Presumably, such factors could vary considerably across relatively short spans of time.

In order to clarify the extent and direction of relationships between psychological factors and cognitive performance in CFS, multiple occasions of measurement are needed to determine whether any co-variation exists. Additionally, physiological functioning, another obvious potential factor in inconsistent cognitive performance, should be assessed in conjunction with psychological functioning. Persons with CFS may not experience dramatic disruptions in their neurological status, but there may be

subtle fluctuations in central nervous system efficiency that are associated with fluctuations in cognitive performance.

The intraindividual approach may be particularly relevant for CFS patients because, theoretically, people with mild cognitive problems or near-normal cognitive performance may fluctuate more than persons with severe cognitive deficits (see Dixon, Hertzog, Friesen, & Hultsch, 1993). Intraindividual variability could partly explain the discrepancy between CFS patients' complaints of cognitive difficulties and the failure to find consistent objective evidence in support of such complaints. To date, intraindividual variability in cognitive functioning has not been examined in this patient group.

The logic of using an intraindividual variability framework to study cognitive functioning in CFS patients becomes evident when one considers the fluctuating nature of this disorder. There is considerable within-person variation in both severity of symptoms and the ability to carry out activities, as demonstrated by Jason et al. (1999). Fluctuations in fatigue and functional capacity can occur over the span of weeks, days, or even hours as was observed in the Smith et al. (1999) study. These studies demonstrated that an increase in the severity of symptoms is associated with poorer physical and cognitive functioning. A single-occasion measurement of cognitive performance in CFS may accurately represent performance at that specific point in time, but the extent to which those same results accurately represent cognitive abilities at another point in time when the severity of symptoms has increased or decreased, is questionable. Generalizing results across time does not account for co-variation of symptoms and performance.

Another topic that merits further exploration is the role of task characteristics in the cognitive performance of CFS patients. As discussed above, task characteristics such

as degree of difficulty have contributed to inconsistent findings in this area. Task characteristics may also interact with intraindividual variability in cognitive performance. This is an important topic because an understanding of how task characteristics are related to intraindividual variability could shed light on why there is such variability in the results of studies examining CFS and cognitive performance. For example, the highly inconsistent findings regarding attention span in CFS patients may be partly due to significant intraindividual variability on such tasks. There may also be patterns of associations between intraindividual variability and particular types of tasks that could be unique to CFS, in which case measuring intraindividual variability on such tasks could serve to aid the diagnostic process.

There is also a need for evaluating intraindividual variability on tasks that yield relatively consistent results, such as reaction time tasks. It is a fairly well-established fact that persons with CFS are slower on such tasks than healthy persons. However, important information may be missing from such results. If there is considerable intraindividual variability on reaction time tasks, then a summary statement that a CFS patient (or group of patients) is slower than healthy counterparts does not necessarily reflect that person's potential capabilities. By measuring performance relative to an individual's own pattern of results rather than at the group level, the range of the individual's potential performance can be better understood. Using an intraindividual variability approach has the added benefit that comparisons at the group level can be easily derived from such an approach whereas a comparison of group means cannot be reduced to provide information at the individual level.

From a clinical perspective, accurate assessment has tremendous implications. Individuals who are assessed when they are at a low point in their cognitive performance may be erroneously diagnosed as having an impairment. This was illustrated by May, Hasher, and Stoltzfus (1993), who noted that time of day may be a critical variable in evaluating intellectual functioning. Alternatively, the cognitive abilities of individuals who are assessed when they are at the peak of their performance may be overestimated (i.e., such results do not accurately reflect the difficulties that may be encountered occasionally or on a fairly regular basis). Misleading results can result in misdiagnosis and create frustration and distress for the patient, as well as lead to inappropriate interventions, failure to address real problems, and have implications with regard to disability claims. Examining intraindividual variability within CFS patients would help clarify whether or not single occasion assessments lead to reasonably accurate results, or whether multiple testing sessions would more accurately capture the full range of cognitive performance. Furthermore, Collins and Long (1996) found that intraindividual variability was a useful marker for distinguishing between nonimpaired persons with traumatic brain injury and a control group. Intraindividual variability may demonstrate the same discriminative power in distinguishing persons with CFS from those without the disorder. Although the present study will not address causes of intraindividual variability, the results will provide groundwork for determining whether or not intraindividual variability is relevant for understanding CFS patients' cognitive difficulties.

Hypotheses

The following hypotheses represent a synthesis of current neuropsychological findings and an intraindividual variability framework:

1. Following from previous research (Grafman et al., 1993; Scheffers, Johnson, Grafman, Dale, & Straus, 1992; Marshall, Forstot, Callies, Peterson, & Schenck, 1997; Smith, Behan, Bell, Millar, & Bakheit, 1993; Smith et al., 1999), it is hypothesized that CFS patients will demonstrate overall slower performance than healthy individuals on tasks that assess latency of responses. Another dimension of performance, accuracy, will also be assessed. Due to the inconsistency of findings in this area, it is unclear whether group differences will emerge with respect to accuracy. The inclusion of comparisons based on accuracy will provide information concerning whether or not CFS patients experience difficulties across different aspects of performance.
2. An emerging body of evidence suggests that persons with some disorders affecting the central nervous system and other physical problems experience greater fluctuations in cognitive functioning than healthy persons (e.g., Stuss et al., 1994). It is expected that this study will reflect previous research involving persons with physical problems in that CFS patients will demonstrate greater intraindividual variability than healthy individuals. In keeping with the finding that greater intraindividual variability is associated with greater latencies across different populations (e.g., Anstey, 1999; Hultsch et al., 2000; Li et al., 2000; Stuss et al., 1994), it is expected that group differences in intraindividual variability will be apparent when performance is defined by latencies. It is less clear whether any group differences will emerge when intraindividual variability in accuracy is examined. The number of studies that have assessed intraindividual

variability and accuracy of performance is very small, but they suggest a weaker relationship than when latencies are considered (Hultsch et al., 2000; Li et al., 2000).

The present study may find a similar pattern of results.

3. Studies that have explored cognitive functioning among CFS patients have yielded inconsistent results, but there is tentative evidence that CFS patients are slower than healthy persons, and their performance declines in relation to increasing task complexity (Wearden & Appleby, 1996). It is unknown whether one factor (response speed demands or greater task complexity) is more strongly related to level of performance than the other. The present study will include a range of tasks that vary in complexity, but it is difficult to predict whether CFS patients will demonstrate greater intraindividual variability than healthy persons on relatively difficult tasks. If response speed and task complexity are equally associated with intraindividual variability, then group differences in intraindividual variability may occur on both relatively simple latency tasks and more complex tasks. If one factor is more closely related to intraindividual variability than the other, then tasks that are characterized by that factor would produce the greatest group differences. The role of task characteristics will be considered when interpreting the results as CFS patients may demonstrate a selective pattern of results with high levels of intraindividual variability occurring on some tasks but not others.

4. There is a minimal amount of research that has examined correlates of intraindividual variability beyond central nervous system functioning, particularly “state” factors, or those that reflect short-term effects in areas such as mood and the amount of stress experienced. In order to further explore possible associations between

intraindividual variability and “state” factors not directly related to neurological status, the following variables will be examined using brief time frames: positive and negative mood states, levels of stress, and levels of physical pain. Given that factors other than physiological variables (e.g., attributions of causality) have been found to play a role in the course of CFS (Heijmans, 1998; Joyce & Wessely, 1996), it is likely that variables that are largely exogenous to central nervous system functioning are important correlates of both performance and intraindividual variability among patients. If such relationships do exist, it is expected that negative affect, along with high levels of stress and pain, would be positively related to greater intraindividual variability in both CFS patients and healthy individuals.

5. Research involving older adults has found a strong, negative relationship between levels and intraindividual variability in physical functioning, and levels and intraindividual variability in cognitive functioning (e.g., Anstey, 1999; Li et al., 2000). The question of the extent to which levels of physiological markers are related to intraindividual variability in cognitive functioning among CFS patients is of interest for two main reasons. First, fluctuations in physical functioning are a hallmark of CFS. If there are associations between physiological measures and intraindividual variability in cognitive performance, then the salience of physical functioning in CFS would suggest that it is an important correlate of intraindividual variability. Second, the absence of co-variation between physical functioning and intraindividual variability in cognitive functioning would suggest independent causal processes. In other words, it would be more likely that separate factors would affect physical and cognitive functioning than a common cause, such as global central nervous system impairments. By definition, CFS

encompasses both cognitive and physical symptoms, and cognitive symptoms do not occur in the absence of physical problems. Given this, it is expected that levels of markers of physical functioning will be inversely associated with intraindividual variability in cognitive performance.

METHOD

Participants

The group of CFS patients consisted of 2 men and 12 women ranging in age from 39 to 74 ($M = 54.67$). The group of healthy individuals was comprised of 7 men and 9 women ranging in age from 29 to 74 ($M = 41.63$). The CFS patients were recruited from the Myalgic Encephalomyelitis Victoria Association. Healthy participants were recruited from a variety of sources including software companies and the computing department at a university. Some healthy participants were acquaintances of CFS patients. Participants were offered individualized feedback regarding their performance in lieu of financial remuneration. The CFS group initially consisted of 17 individuals but 3 persons did not complete the study.

Screening and initial data collection.

An initial telephone screening interview was conducted with all potential CFS participants. The purpose of this interview was to determine whether or not the person met the research criteria defined by Fukuda et al. (1994; see Appendix A). Participants in the CFS group were also required to provide documentation from a physician confirming the diagnosis. All participants, both healthy persons and those with CFS, were administered an in-person interview. Before beginning the interview process, participants were provided with a written description of the study including their rights as participants. Informed consent was obtained in writing before proceeding with the interview.

One purpose of the interview was to ensure that all participants were free of conditions that would likely confound the study's results. Persons with a history of

extensive drug/alcohol abuse, medical illnesses affecting the central nervous system (e.g., Parkinson's disease), head trauma or psychiatric illnesses that required hospitalization were excluded from this study. Participants provided demographic information during the interview as well as perceptions of health status, and objective information regarding health status and illness behaviours.

A summary of demographic information appears in Table 1. There was no significant difference between the groups with respect to years of formal education; the CFS group averaged 16.5 years and the average within the control group was 15.3. There was a significant group difference with respect to age, $F(1,28) = 12.13$, $p < .01$, $\eta^2 = .30$, with the average age emerging as greater within the CFS group than the control group ($M = 55.6$, $SD = 10.0$ vs. $M = 41.6$, $SD = 11.7$). Table 2 presents descriptive information concerning health status. Participants with CFS reported poorer health and a greater impact of poor health on their activities than their healthy counterparts.

A battery of tests was also administered during the initial interview. Results are presented in Table 3. Cognitive measures including the Block Design and Vocabulary Subtests from the Wechsler Adult Intelligence Scale-III (WAIS-III; Psychological Corporation, 1997) were administered to obtain rough estimates of non-verbal and verbal intellectual functioning. Age-adjusted estimates of full-scale IQ scores (Sattler & Ryan, 1999) were calculated based on these two Subtests. The North American Adult Reading Test (NAART; Blair & Spreen, 1989) was used to determine an estimate of premorbid intelligence in the CFS group. A third measure used to assess cognitive functioning was the Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975). A cutoff score of 26 was used to screen for persons with possible cognitive impairments.

Table 1

Participants' Demographic Information

Demographic Variable/Category	CFS Patients	Healthy Participants
Age ^a	55.6	41.6
Years of Education ^a	16.5	15.3
Marital Status ^b		
Single/never married	40.0	12.5
Married/common-law	40.0	68.8
Separated/divorced	20.0	18.8
Employment Status ^b		
Currently employed	6.7	87.5
Currently unemployed	93.3	12.5
Type of Current or Past Occupation ^b		
Professional/technical	58.3	68.8
Manager/administration/clerical/sales	41.7	31.3

^aFigures are means.

^bFigures are percentages.

Table 2

Self-Reported Health

Health Indicator	CFS Patients	Healthy Participants
How is your current health in general?		
Very good	0	37.5
Good	13.3	62.5
Fair	53.3	0
Poor	20	0
Very poor	13.3	0
Compare to others your age, your current level of health is:		
Very good	0	25.0
Good	6.7	56.3
Fair	6.7	18.8
Poor	66.7	0
Very poor	20.0	0
Number of nights in hospital over past year:		
0 – 2	93.3	100.0
3 – 5	6.7	0

Note. Figures denote percentages.

table continues

Health Indicator	CFS Patients	Healthy Participants
Number of visits to physician over past year:		
0 – 4	13.4	100.0
5 – 9	33.3	0
10 – 14	33.3	0
more than 14	20.1	0
Number of days sick in bed over past year:		
0 – 4	26.6	93.8
5 – 9	0	6.3
10 – 14	13.4	0
more than 14	67.0	0

Note. Figures denote percentages.

Table 3

Benchmark Measures of Cognitive Functioning

Variable		Group	
		CFS	Healthy
MMSE	<u>M</u>	29.44	29.87
	<u>SD</u>	0.18	0.17
NAART	<u>M</u>	21.59	19.99
	<u>SD</u>	3.36	3.11
Estimated NAART IQ	<u>M</u>	110.96	112.21
	<u>SD</u>	2.62	2.42
WAIS-III Block Design	<u>M</u>	39.55	47.15
	<u>SD</u>	3.32	3.07
WAIS-III Vocabulary	<u>M</u>	52.87	53.30
	<u>SD</u>	2.30	2.12
Estimated WAIS-III Full Scale IQ	<u>M</u>	110.34	118.02
	<u>SD</u>	3.99	3.69

Note. Means are adjusted for age.

The lowest scores in the CFS group was 28, and the lowest score among healthy individuals was 29. Because of the significant age difference between the groups, age was used as a covariate in comparing the groups' performance on the cognitive benchmark measures. The only significant group difference emerged on Block Design, with healthy participants scoring higher than CFS patients, $F(2,27) = 4.45$, $p = .05$, $\eta^2 = .25$.

In order to screen for potential group differences with respect to the degree of effort put forth during the testing, The Victoria Symptom Validity Test (VSVT; Slick, 1996) was administered to provide an index of effort as well as the degree of exaggeration of cognitive difficulties. The VSVT is a computerized task in which a five-digit number appears on a screen. After a five-second time period, the number disappears and then two more numbers, the original and a foil, appear. The length of time between presentation of the target and the response choices is 5, 10, or 15 s. There are 48 trials divided equally into three blocks based on the different retention intervals. Item difficulty also varies, with some trials consisting of a foil number that is identical to the target number except for one digit. Biased performance is cued by informing the participant that it is a difficult task for persons with memory problems, and that difficulty increases as the retention interval between studying the target and identifying it from the two choices increases. Internal reliability (as measured by Cronbach's alpha) has been found to be .89, and a test-retest reliability coefficient of .73 has been reported (Slick, as cited in Spreen & Strauss, 1998).

The VSVT was administered on the first, third, and fifth occasions. A comparison of VSVT scores revealed no group differences between CFS patients and

healthy participants. Both groups performed more poorly on the more difficult condition, $F(1,15) = 23.46, p < .001, \eta^2 = .61$. The effect of difficulty did not suggest any exaggeration of cognitive difficulties.

Procedure

Participants were tested on ten separate occasions between August and November of 1999. Most sessions were scheduled on an approximately weekly basis and lasted from 40 to 80 minutes. Rather than following a set schedule so that participants were tested at the same time on the same day every week, sessions were scheduled at a variety of times (from early morning to late evening) and on different days of the week. In order to accommodate participants' schedules and vacations, time intervals between sessions generally ranged from 2 to 14 days, with a maximum of 59 days.

Participants were given the option of being tested in their homes or at the University of Victoria. Most participants chose to be tested in their homes. Initial testing sessions lasted approximately 75 minutes. Later testing sessions were shorter in duration due to the participants' increased familiarity with testing procedures. Tasks were administered in the same order to all participants on all testing occasions.

Measures

A battery of tests was designed to assess cognitive performance and correlates of cognitive performance. Possible correlates of cognitive performance that were assessed included affective and somatic factors such as mood states, physical pain, and daily stressors, and biological markers of physiological functioning including hand grip strength, blood pressure, and balance tasks. Cognitive tasks included measures of reaction time, executive functions and attention, episodic memory, and vocabulary. The

cognitive tasks varied in terms of complexity and are presented in the following section in order of relative difficulty, from the simplest task to the most difficult.

Cognitive Measures

Simple reaction time (SRT). In this computerized task, participants were asked to press a key with their dominant hand as quickly as possible, while maintaining accuracy, following the presentation of a cross in the middle of the computer screen. The latency of each response was recorded by the SRT program. Each presentation of the cross was preceded by a visual warning stimulus consisting of three dots arranged in a row to focus the participant's attention. Ten practice trials were administered. After the practice trials, 50 test trials were administered. The test trials were divided into 5 blocks of 10 trials each. In each block, trials were randomly presented based on five intervals between the warning stimulus and the presentation of the figure: 500, 625, 750, 875, and 1000 ms. The latencies of all 50 trials were used as the measures on this task. No accuracy data were generated by this task.

Choice reaction time (CRT). This computerized task required participants to choose as quickly as possible between two possible targets while maintaining accuracy. A warning stimulus consisting of two crosses, one to the left and one to the right of the centre of the computer screen, was presented before each trial. After an interval of 1000 ms, one cross changed into a square. Participants had to press a key corresponding to the position of the square as quickly as possible. Ten practice trials were administered. The test trials were divided into 5 blocks of 10 trials each, with the location of the square randomised across all trials for an equal number of presentations on the right and left

sides. The measures provided by this task were the latencies and percent of correct responses for the 50 test trials.

Visual search task (VST). A visual search task modeled after one developed by Moore and Egeth (1998) was used. Participants were asked to determine whether a number appeared within a group of letters presented on a computer screen. A warning stimulus appeared for 500 milliseconds in the centre of the screen to focus the viewer's attention prior to the presentation of the letters. Each trial consisted of letters appearing in a matrix format. Moore and Egeth excluded the following letters due to their similarity to numbers: B, I, O, and R. These letters were also omitted from the present search task. The letters were in Helvetica font, uppercase, and were roughly 1 cm in size. Neighbouring characters were separated by approximately 1 cm.

A target number was selected randomly to appear on half of the trials. The set of possible targets included 2, 4, 6, 7, and 9. There were three levels of difficulty: "easy" consisted of a 3 X 3 matrix; "moderate" consisted of a 5 X 5 matrix; and "difficult" consisted of a 7 X 7 matrix. The letters and targets for each trial were selected randomly, as were their positions within the matrix.

Participants were asked to press one of two keys depending on whether or not a target was present. The matrix remained visible until a response occurred. Participants were instructed to complete the task as quickly as possible while maintaining accuracy. The warning stimulus reappeared 1200 ms after each response. Two practice trials were administered before 60 test trials. The test trials were divided equally across the three levels of difficulty and presented in a random order on each occasion. (Due to a

computer error, responses on the last trial were not recorded, resulting in a total of 59 test trials.)

Stroop. This commonly used test assesses how easily an individual can shift perceptual set to accommodate competing demands and suppress a prepotent response. The Victoria version (Regard, 1981) consists of three conditions that vary in difficulty. In the first part (hereafter referred to as Stroop – dots), general reaction speed is measured by asking the participant to name the colours of 24 dots printed on a card in green, blue, red, or yellow. The participant is then given another card (Stroop – word) on which there are 24 simple words (e.g., “when”), each one printed in one of the four colours. The participant is asked to name the colours of the words as quickly as possible. In the third section (Stroop – colour), a card with the words “green, blue, red, yellow” are printed but not in their corresponding colour. Again, the participant must quickly name the colours of the words. This is the most difficult condition within the task. The time taken to finish each card and the number of errors are recorded. Latency data from each of the three Stroop conditions were used as measures in the present study. Spreen and Strauss (1998) note that individuals tend to show significant practice effects on the Stroop when tested over time, but suggest that this is not problematic if it is the pattern, not mean level, of scores that are of interest.

Episodic memory (Word). Participants were read a list of 12 common nouns to be memorized. Immediately following the presentation of the list, participants were asked to recall as many words as possible, in any order. Following a three-minute delay during which a visual interference task was administered, participants were again asked to recall as many words as possible from the list. After approximately 15 minutes,

participants were then given a computerized recognition task. A total of 24 words (the 12 list words interspersed with 12 distractors) were presented, one at a time.

Respondents were told to press one of two keys to indicate whether the word on the screen was one they had heard previously on the list or whether it was a new word.

Word length varied from four to nine letters. Ten forms of this measure were developed and pilot tested to ensure equivalent difficulty across forms. The measures used from this task were latencies and the number of words correctly identified as new or old from the computerized recognition task.

Weekly vocabulary. Participants were given a vocabulary test that required them to select the correct definition for a target word (Ekstrom, French, Harmon, & Dermen, 1976). Each target word was accompanied by five possible definitions. Ten forms of this measure were developed to ensure uniform difficulty across different forms. This measure was included to help determine if CFS patients experience variability in unexpected domains, as knowledge of word meanings is a relatively robust cognitive ability. For purposes of clarity, this task will be referred to as ‘weekly vocabulary’ in order to distinguish it from the WAIS-III Vocabulary Subtest administered only during the intake with the other cognitive benchmark measures described earlier.

Affective/Somatic Measures

Daily Stress Scale. This checklist reflects stressors that occur frequently and have been found to be associated with daily moods (Bolger & Schilling, 1991). It consists of 14 items that cover domains such as interpersonal stressors, unexpected events, and high levels of demands on personal resources. Respondents indicate which stressors they have experienced within the past 24 hours. Higher numbers of stressors

indicate greater levels of stress. An additional series of items was included with this questionnaire to identify persons (e.g., neighbour, friend) that contributed to stressful interpersonal contact(s) in the 24 hour period preceding the testing session. The total number of stressors was calculated for each participant by summing the number of stressors experienced on the original 14-item checklist with the number of persons identified as sources of stress.

Pain Questionnaire. This questionnaire is an amalgamation of the McGill Pain Questionnaire (Dubuisson & Melzack, 1976) and the Medical Outcomes Study Pain Measures (Sherbourne & Meredith, 1992). It assesses the frequency, duration, and intensity of any pain experienced by the respondent. Functional disability due to pain is measured in six different domains, including mobility and enjoyment of life. A five-point scale with possible responses ranging from “not at all” (1) to “extremely” (5) is used to rate the extent to which pain interfered with functioning over the past week. Respondents use a 20-point scale to indicate the amount of pain they are experiencing at that moment as well as the average amount of pain experienced over the past week. These latter two measures, amount of pain experienced in the present moment and the average amount of pain experienced over the preceding week, were used in the present study.

Positive and Negative Affect Schedule (PANAS). This scale consists of a list of 20 adjectives, equally divided to represent positive and negative mood states (Watson, Clark, & Tellegen, 1988). Examples include “ashamed” and “enthusiastic.” Participants use a 5-point scale to rate the extent to which each adjective describes their current mood state (alternate instructions can be used to query mood states on the day of testing or in

the recent past). Response options range from “very slightly or not at all” (1) to “extremely” (5). Two scores are calculated: one is a summation of response values for positive adjectives and the other is a summation of response values for negative adjectives. When used to assess current mood states, the PANAS has been found to yield an internal reliability coefficient of .89 for positive adjectives, an alpha coefficient of .85 for negative adjectives, and test-retest correlation coefficients of .54 (positive adjectives) and .45 (negative adjectives) over an eight-week interval (Watson et al., 1988).

Biomarkers

Blood pressure. Systolic and diastolic arterial pressure, as well heart rate, was obtained using a sphygmomanometer. Digital readings were taken by placing the blood pressure cuff on the upper portion of participants’ arms. The right arm was used except on occasions when participants specifically requested that the left arm be used.

Hand grip strength. Grip strength was measured using a dynamometer. The upper portion of this device is held in one hand, with the participant’s arm held parallel and slightly away from the body. The participant squeezes the stirrup of the dynamometer and pressure is recorded in kilograms. One measurement was taken for each hand with the dominant hand tested first.

Sensorimotor performance. Sensorimotor performance was measured by two mobility tasks commonly used in studies of aging and cognitive performance (e.g., Li, Aggen, Nesselroade, & Baltes, 2000). The “turning task” required participants to walk in a 360-degree circle using a minimum of steps. The number of steps was recorded. The “walking task” consisted of having individuals walk in a straight line 10 feet long as quickly as possible. The time taken to complete the walk was recorded in milliseconds.

Data Screening and Preparation

Data from the computerized tasks were initially grouped by participant and occasion number and scatterplots were used to identify violations of normality. A review of all response latencies revealed some unusually low values, raising the possibility that such values reflected aberrations in response times rather than true latencies. For example, it would be virtually impossible to respond to the target stimulus in the SRT within 40 ms of its presentation. A response latency this small would likely indicate an error such as an accidental key press instead of reacting to the target as directed. In order to eliminate the influence of extremely low (and unlikely) response latencies, the following minimum values were established: SRT – 150 milliseconds; CRT – 150 milliseconds; VST – 300 milliseconds; Word – 300 milliseconds. Response times below these minimum values were excluded from further analyses. In order to identify and eliminate unusually long response latencies, the means and standard deviations for each group in each session were calculated. Values that met or exceeded three standard deviations above the mean were excluded. The amount of data excluded from further analyses based on these upper and lower boundaries was as follows: SRT – 2.9%; CRT – 2.2%; VST – 3.5%; Word – 0.67%.

After eliminating extreme values, a regression substitution method was used to compute replacement values for missing data based on covariances among responses across trials and occasions. The more traditional method of replacing missing data with a mean value was not appropriate for the present study as doing so would mask intraindividual variability in scores. However, eliminating extreme values and imputing

missing data as described represents a conservative method of data screening as these approaches would underestimate variability to some extent.

RESULTS

A preliminary step involved computing a 2 (Group) X 3 (Difficulty) ANOVA using the VST. This analysis revealed that level of difficulty did not have an effect on response times as CFS patients were significantly slower than healthy participants across all three conditions [$F(1,2) = 1641.59, p < .001, \eta^2 = .09$]. Data were collapsed across the levels of difficulty for all analyses.

Initial analyses focused on group differences in performance as defined by latency and accuracy scores. As part of these analyses, the relative contributions of external factors (group, occasion and trials within each occasion) vs. intraindividual variability to performance scores were determined. The effects of these external factors were partialled from the data and intraindividual standard deviations were then calculated as primary measures of intraindividual variability. Coefficients of variation were calculated as additional markers of intraindividual variability. Group differences in intraindividual variability were examined both within and across testing occasions. Differences in intraindividual variability across tasks were also investigated. The next set of analyses consisted of correlations used to determine relationships between intraindividual variability and level of performance on cognitive tasks; intraindividual variability on a given occasion and across all occasions; and the extent to which intraindividual variability on each task was related to intraindividual variability on other tasks. Correlational analyses were conducted to evaluate relationships between cognitive performance, intraindividual variability, and biomarkers and affective/somatic predictors. (Intraindividual variability in predictors was not examined for the purposes of this

paper.) Finally, discriminant function analyses were conducted to determine the relative contributions of performance and intraindividual variability to predicting group membership. All analyses were performed separately for latency and accuracy data. Because of the significant group difference with respect to age, and because age has been found to be associated with intraindividual variability (e.g., Shammi, Bosman, & Stuss, 1998), age was used as a co-variate in analyses comparing group means. Correlations between age and measures of intraindividual variability ranged from .08 to .47.

Level of Performance

Response latency data. Group differences in mean levels of performance were first examined on the latency data. Mean latency values for all tasks are presented in Table 4. Separate Group X Occasion X Trial ANCOVAs were conducted using data from the CRT, SRT, VST, and Word. Occasion and Trials were designated as within-subjects factors, and Group was the between-subjects factor. Trial data were collapsed into blocks of five rather than individual trials to accommodate computer processing limitations. A Group X Occasion X Difficulty ANCOVA was calculated to analyze level of performance on the Stroop, with Group serving as the between-subjects factor and Occasion and Difficulty (c.f., the 3 Stroop conditions vary in degree of difficulty) designated as within-subjects factors.

There was a significant Group main effect for all five measures: SRT, $F(1,27) = 14.72$, $p < .01$, $\eta^2 = .35$; CRT, $F(1,27) = 10.34$, $p < .01$, $\eta^2 = .28$; VST, $F(1,27) = 17.90$, $p < .001$, $\eta^2 = .40$; Stroop, $F(1,27) = 9.02$, $p < .01$, $\eta^2 = .25$; Word, $F(1,27) = 11.33$, $p < .01$, $\eta^2 = .30$. CFS patients consistently demonstrated slower performance than the healthy participants. A significant effect of Occasion was observed: CRT, $F(9,243) =$

Table 4

Mean Latency Scores

Variable	Group	
	CFS	Healthy
SRT	451.36	319.64
CRT	531.28	424.75
VST	1850.41	1219.56
Stroop – Dots	12842.40	10247.10
Stroop – Words	15312.10	12115.80
Stroop – Colours	28046.30	17225.00
Word	1447.89	1101.62

Note. Mean latency scores are measured in milliseconds and are adjusted for age.

2.27, $p < .05$, $\eta^2 = .08$; Stroop, $F(9,243) = 3.19$, $p < .01$, $\eta^2 = .11$. In general, latencies became shorter over occasions on both of these tasks.

Several interactions were found. A Group X Occasion interaction was found on the SRT, $F(9,243) = 2.30$, $p < .05$, $\eta^2 = .08$, reflecting increasing group differences across occasions. On the CRT, the following interactions emerged: Group X Occasion: $F(9,243) = 2.78$, $p < .01$, $\eta^2 = .09$; Occasion X Trial: $F(81,2187) = 1.87$, $p < .001$, $\eta^2 = .06$; Group X Occasion X Trial: $F(81,2187) = 1.90$, $p < .001$, $\eta^2 = .07$. CFS patients produced consistently greater latencies than healthy participants. Group differences did not vary with trials on earlier occasions, but they occurred mainly on middle trials on later occasions. The VST produced a significant Group X Occasion X Trial interaction: $F(99,2673) = 2.00$, $p < .001$, $\eta^2 = .07$. This interaction reflected a trend toward decreasing latencies across occasions, with CFS patients tending to show a greater decrease than healthy individuals. Also, latencies tended to increase across trials (within each occasion) for CFS patients but not healthy participants.

The following interactions were found on the Stroop: Group X Difficulty: $F(2,54) = 4.93$, $p < .05$, $\eta^2 = .15$; Group X Difficulty X Occasion: $F(18,486) = 2.06$, $p < .01$, $\eta^2 = .07$. Both groups demonstrated a decrease in latencies across occasions. On the Stroop – colour task, the decrease was more pronounced among the CFS patients than the healthy participants. The CFS group consistently performed more slowly than the healthy group, but the magnitude of the group difference varied by level of difficulty and occasion. Group differences were most pronounced on the first three occasions and remained fairly constant following a sharp decrease on the fourth occasion. On the Stroop – dots task, group differences were smaller on the second occasion than the first occasion, but

increased fairly steadily across subsequent occasions. The Stroop – word task produced the same pattern of group differences, but the disparity between group performances did not increase to the same extent as on the dots task. Finally, increasing group differences across occasions resulted in a significant Group X Occasion interaction on Word, $F(9,243) = 2.88, p < .01, \eta^2 = .10$.

Accuracy data. Table 5 presents mean accuracy data adjusted for age. Separate Group X Occasion ANCOVAs were performed using the accuracy scores from the CRT, Stroop, VST, Word, and Weekly Vocabulary tasks. A main effect of Group emerged on the CRT, but a Group X Occasion interaction was also found: $F(9,225) = 3.40, p < .01, \eta^2 = .12$. Only the 10th occasion produced significantly higher means within the CFS group. A main effect was associated with Occasion on Weekly Vocabulary: $F(9,216) = 2.11, p < .05, \eta^2 = .08$. Participants in the CFS group were consistently more accurate than healthy participants, but group differences were most apparent on occasions five through ten.

Transformation of Data

The above findings demonstrate that group, occasion, and trial were associated both independently and in various combinations with performance. The effects of occasion and trial may be thought of as relatively irreversible, or systematic. For example, practice effects would more than likely have occurred both within and across sessions, causing increased task familiarity that could have affected performance. These types of effects are cumulative, accounting for relatively long-lasting and systematic changes in performance that are independent of intraindividual variability. By definition,

Table 5

Mean Accuracy Scores

Variable	Group	
	CFS	Healthy
CRT	99.79	98.82
VST	97.22	98.33
Stroop ^a – dots	99.58	99.87
Stroop – word	99.82	99.92
Stroop – colour	98.35	99.87
Word	80.28	80.84
Weekly Vocabulary	72.8	60.65

Note. Accuracy scores represent percent correct responses and are adjusted for age.

^aThe Group X Occasion ANCOVA for the Stroop revealed an absence of variation among scores on this task. The lack of variation indicated that accuracy on the Stroop could not be associated with age. Accordingly, means for the Stroop are not adjusted for age.

intraindividual variability refers to short-term fluctuations in an individual's functioning that are separate from more permanent changes in functioning. Because performance is affected by systematic influences such as occasion and trial, it is necessary to remove these effects from performance data in order to examine intraindividual variability. If the effects of occasion and trial were not removed, any analyses of intraindividual variability would be confounded by these effects. Also, the observed significant group differences could serve as another source of systematic error in the analysis of intraindividual variability. Larger means are associated with larger standard deviations, and it is possible that significant mean group differences in intraindividual variability could arise as a statistical artifact due to mean group differences in performance.

In order to analyze intraindividual variability, the effects of major sources of potential systematic error were removed statistically. The effects of trials, occasions, and groups were controlled for by transforming a file containing data for each individual for each trial and session into a single vector. Using this vector, the main effects of trials, occasions, and groups, as well as all interactions, were calculated and partialled out of response latency values. (Trials was not a relevant source of variation for the Stroop and Vocabulary tasks as these tasks consist of single scores only. Accordingly, the effects of occasion and group were removed from data from these tasks.) This resulted in residual scores free from the effects of group differences and increased task familiarity. These residual scores were then converted to T-scores to provide a common metric for comparing results across tasks. For purposes of clarity, these data are referred to as "purified" to reflect the removal of variance due to factors other than intraindividual

variability. By removing variability due to systematic sources, any remaining variability in the data could be ascribed with confidence to intraindividual variability.

Figure 1 presents the residual T-scores for the SRT on Occasion 1 for each group. These graphs illustrate that, even after partialing systematic effects from latency scores, considerable intraindividual variability remains. Furthermore, a potential group difference is evident in that individuals in the CFS group appear to demonstrate greater fluctuations in performance than the healthy group.

Using the purified T-scores, intraindividual standard deviations (ISDs) were calculated as measures of intraindividual variability. The ISDs directly reflected how much an individual deviated from his/her own average performance. Coefficients of variation (CVs) were also calculated. A CV is computed by dividing an individual's ISD by her/his mean score. A CV, then, provides another index of intraindividual variability relative to the individual's own performance, with larger values representing greater intraindividual variability.

Intraindividual Variability Analyses

Intraindividual variability was examined both within occasions (across trials) and across testing occasions. The work of Smith et al. (1999) demonstrated that CFS patients experienced a change in cognitive performance over the course of one testing session, underscoring the need to examine intraindividual variability within a single occasion. Shifts in performance over the time frame of 10 occasions were also of interest as it was possible that a longer time frame would better represent the full range of intraindividual variability.

Intraindividual variability in latency across trials. Mean latency ISD values

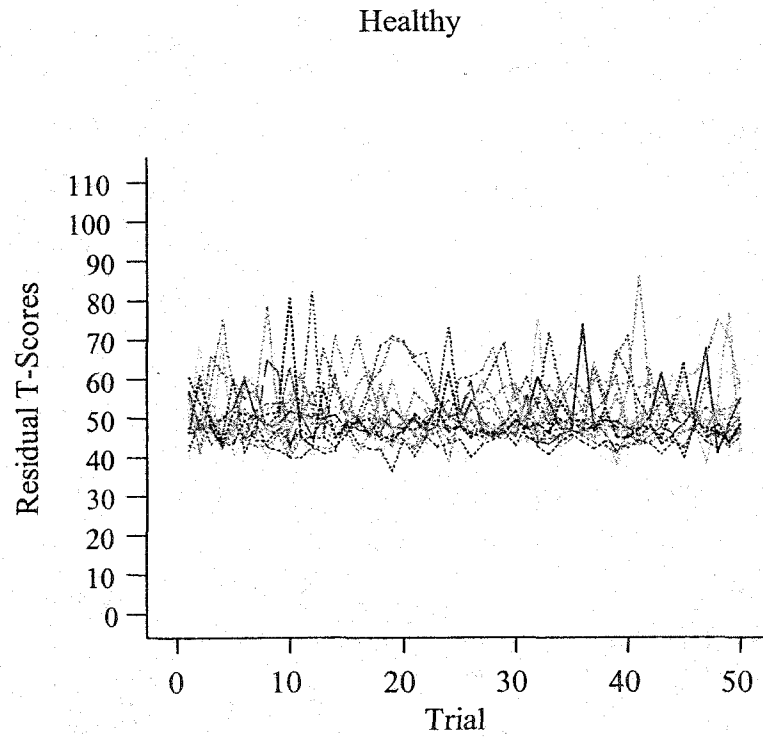
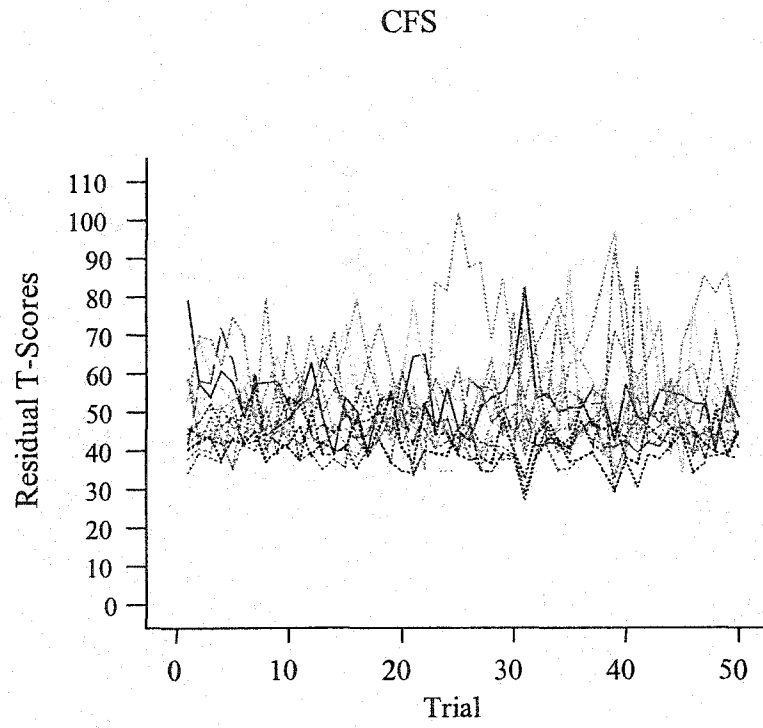


Figure 1. Occasion 1 residual T-scores on the SRT by group.

across trials are presented in Figure 2. A 2 (Group) X 10 (Occasion) MANCOVA was run using the across-trial latency ISDs. The dependent measures included the SRT, CRT, VST and Word but not the Stroop as the Stroop consists of single scores rather than multiple trials (i.e., there were no across-trial reaction times for the Stroop). There was an overall group difference, with participants in the CFS group demonstrating greater intraindividual variability than the control group: $F(4,276) = 37.46, p < .001, \eta^2 = .35$. There was also an effect of Occasion on intraindividual variability in overall performance, with variability increasing across occasions: $F(36,1036) = 3.70, p < .001, \eta^2 = .11$. A significant Group X Occasion interaction indicated that group differences increased across occasions: $F(36,1036) = 2.03, p < .001, \eta^2 = .06$.

Group means for each task on each occasion are presented in Figure 3.

Univariate analyses revealed that greater intraindividual variability occurred within the CFS group on all tasks: SRT: $F(1,279) = 95.07, p < .001, \eta^2 = .25$; CRT: $F(1,279) = 8.66, p < .01, \eta^2 = .03$; VST: $F(1,279) = 68.61, p < .001, \eta^2 = .20$; Word: $F(1,279) = 9.94, p < .01, \eta^2 = .03$. The effect of Occasion was significant for all tasks except Word: SRT: $F(9,279) = 3.19, p < .01, \eta^2 = .09$; CRT: $F(9,279) = 2.22, p < .05, \eta^2 = .07$; VST: $F(9,279) = 8.57, p < .001, \eta^2 = .22$. A significant increase in group differences across sessions was true of the SRT: $F(9,279) = 3.60, p < .001, \eta^2 = .10$, and the CRT: $F(9,279) = 3.16, p < .01, \eta^2 = .09$. Greater intraindividual variability was observed within the CFS group on the CRT task on occasions 1, 7, and 8 only.

The above analyses were repeated using the CV instead of the ISD as a measure of intraindividual variability and the same pattern of results was obtained.

Intraindividual variability in latency across occasions. ISDs were also calculated

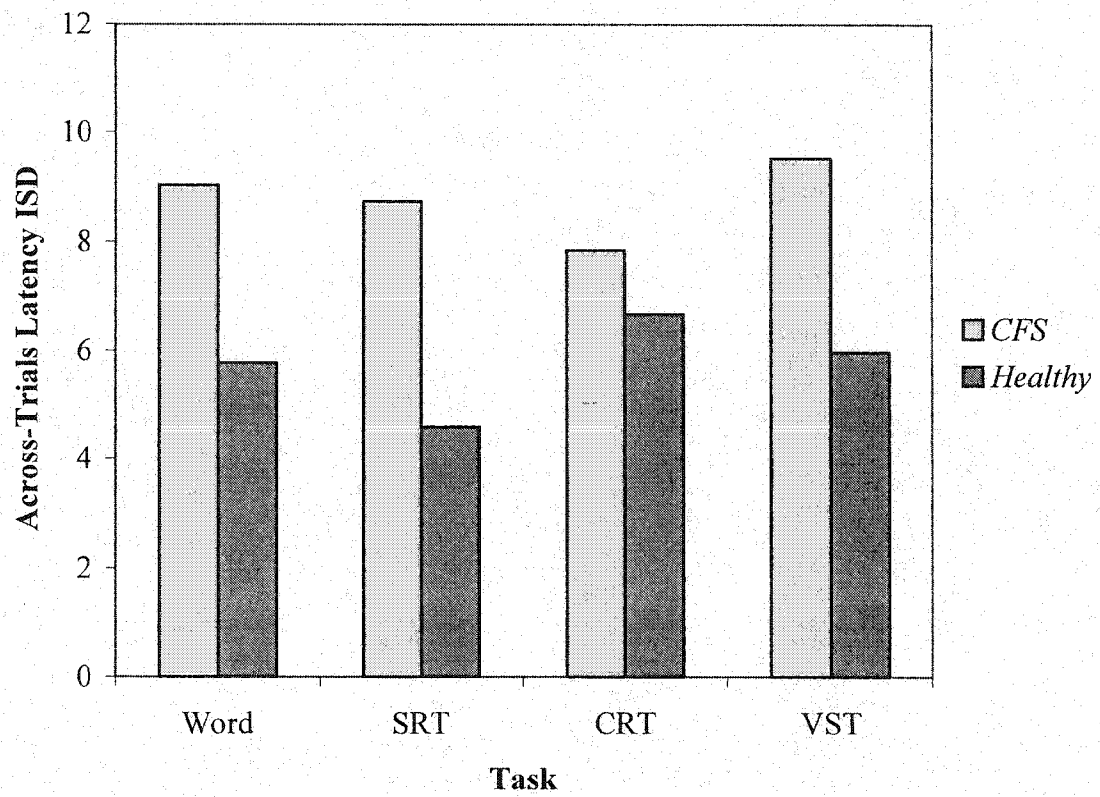


Figure 2. Average across-trials latency ISDs.

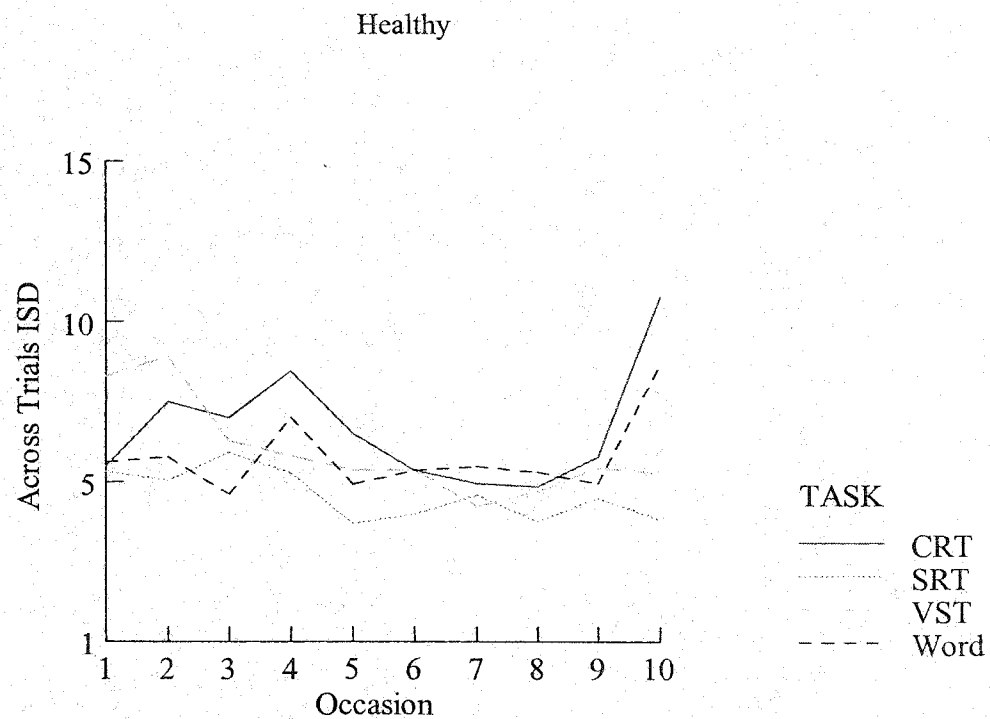
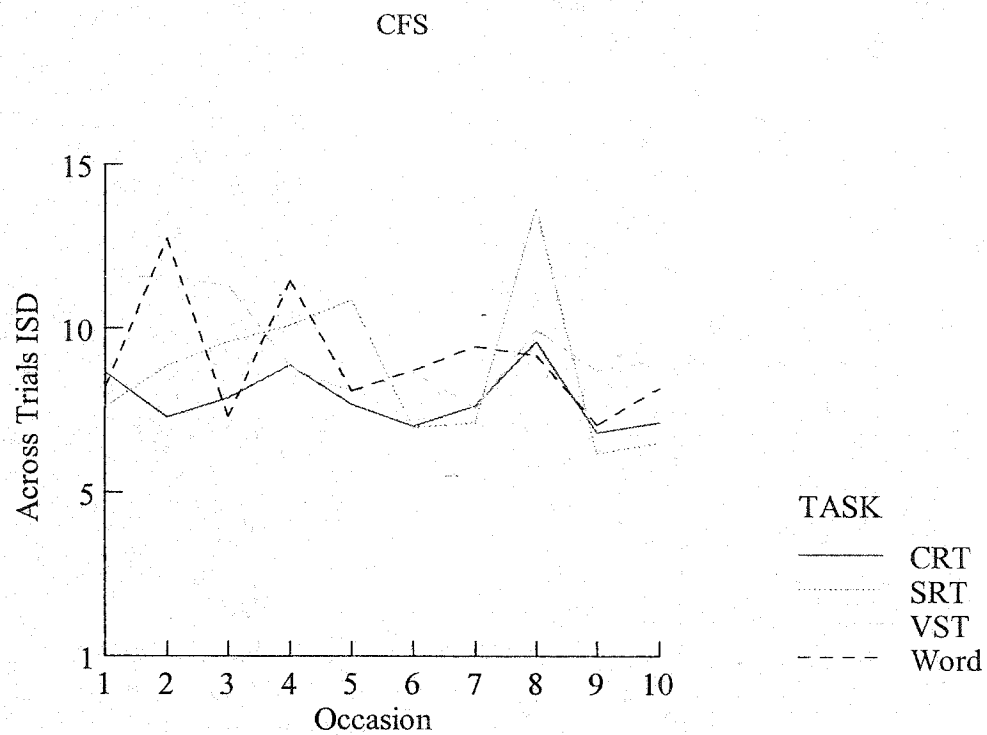


Figure 3. Average across-trials latency ISDs by occasion.

based on each person's responses across occasions. This was done by calculating each person's average latency score across trials for each occasion, and then computing an ISD based on the results. This set of analyses included data from the three Stroop tasks.

Mean across-occasion ISD values are presented in Figure 4. A one-way MANCOVA revealed a significant overall group difference, $F(7,21) = 3.55, p < .05, \eta^2 = .542$, with the CFS demonstrating greater across-occasion intraindividual variability than their healthy counterparts. Significant group differences occurred on the Stroop – dots, $F(1,27) = 8.16, p < .01, \eta^2 = 0.23$, and Stroop – word, $F(1,27) = 5.96, p < .05, \eta^2 = .18$. The same pattern of results was obtained using CVs as measures of intraindividual variability.

Intraindividual variability in accuracy across occasions. Intraindividual variability in accuracy was tested using data from the Word and Weekly Vocabulary tasks. Accuracy data from the other measures were excluded as most scores were at ceiling levels, indicating negligible variability. A 2 (Group) X 3 (Task) mixed ANCOVA revealed a significant group difference on Weekly Vocabulary: $F(1,27) = 6.48, p < .05, \eta^2 = 0.19$, with the CFS group demonstrating greater variability in accuracy than the healthy group ($M = 5.16, SD = 0.32$ vs. $M = 3.94, SD = 0.30$). Using CVs as measures of intraindividual variability yielded the same pattern of results.

Correlational Analyses

Correlations among the ISD data were computed in order to determine if persons who were highly variable on a given task tended to be highly variable on other tasks, and to determine if variability across trials was associated with variability across occasions.

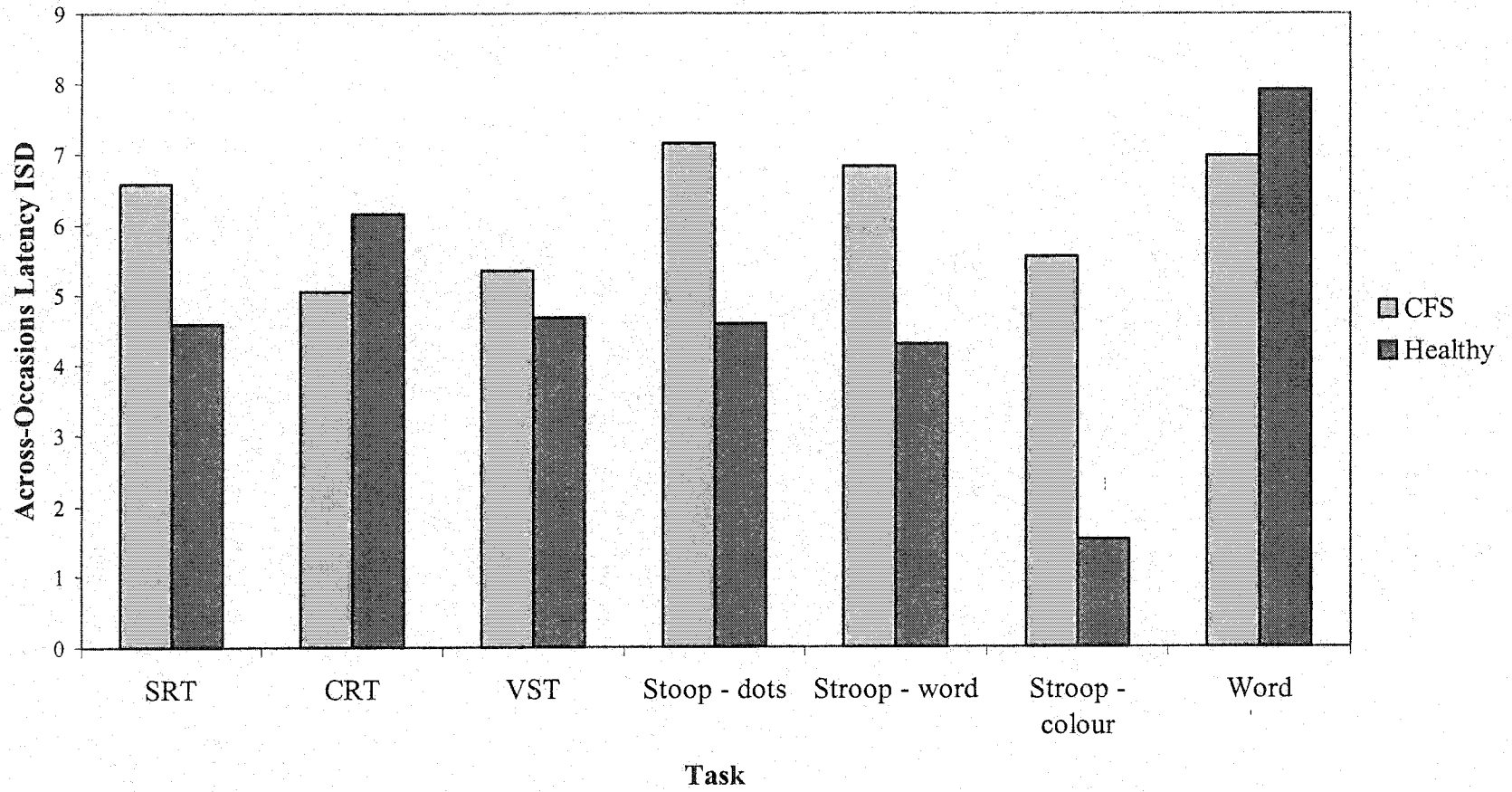


Figure 4. Average across-occasions latency ISDs.

To make the results of these analyses more readily interpretable, across-trial data were averaged rather than reporting separate results for each of the 10 occasions. The results of correlations based only on across-trials data are presented in Table 6. All correlations were positive and ranged in magnitude from .27 to .74. Not all coefficients achieved statistical significance, but this could well be a function of small sample sizes rather than an absence of across-task associations in intraindividual variability. Results based on the SRT were consistent, with high variability on this task being associated with high variability on all other across-trials tasks. It appears that intraindividual variability on a particular task within a testing occasion was related positively to intraindividual variability on all other tasks within that same occasion.

Table 7 consists of the results of across-occasions correlations. These results were somewhat more inconsistent than those based on across-trials data, with correlations ranging from -.12 to .75. The mean values of correlation coefficients were calculated for each task (using absolute values) and the lowest mean correlation, .17, was based on the Word task. The largest mean correlation, .46, pertained to the Stroop – dots task. Thus, the extent to which intraindividual variability on a task can predict intraindividual variability on other tasks on other occasions varies considerably depending on which pairs of tasks are considered. The Word task appears to be a relatively weak predictor of variability on other tasks across occasions, whereas the Stroop – dots task is a relatively stronger indicator, at least for this population.

All correlation coefficients were positive when across-trials data were compared with across-occasions data. Results are provided in Table 8. High variability on a particular task within an occasion was associated with high variability on the same task

Table 6

Intercorrelations Among Across-Trials Latency ISD's

Variable	(1)	(2)	(3)	(4)
(1) SRT	---			
(2) CRT	.74**	---		
(3) VST	.52**	.34	---	
(4) Word	.55*	.27	.47**	---

* $p < .05$. ** $p < .01$.

Table 7

Intercorrelations Among Across-Occasions Latency ISD's

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) SRT	---						
(2) CRT	.64**	---					
(3) VST	.31	.07	---				
(4) Stroop - Dots	.75**	.26	.51**	---			
(5) Stroop - Words	.38*	.05	.35	.50**	---		
(6) Stroop - Colours	.34	-.12	.41*	.57**	.24	---	
(7) Word	.12	.37*	.21	.19	.07	-.05	---

* $p < .05$. ** $p < .01$.

Table 8

Correlations of Across-Trials and Across-Occasions Latency ISD's

ISD Measure Across Trials	ISD Measure Across Occasions						
	SRT	CRT	VST	Stroop – Dots	Stroop – Words	Stroop – Colours	Word
SRT	.68**	.16	.41*	.73**	.54**	.53**	.11
CRT	.71**	.55**	.33	.58**	.46*	.41	.25
VST	.36*	.07	.44*	.54**	.54**	.40*	.19
Word	.21	.00	.23	.39*	.24	.25	.52**

* $p < .05$. ** $p < .01$.

across occasions; these values ranged from .44 to .68. Overall, relationships were weaker when across-task comparisons were made, with results ranging from 0 to .73.

Individuals who were highly variable on the Stroop – dots task across occasions were also highly variable on all across-trials tasks. Intraindividual variability on the Word task produced the weakest associations with variability on other tasks across time frames. In summary, variability on the same task was consistent across occasions. Variability on a given task was predictive of variability on other tasks across time frames, but the magnitude of the relationship differed considerably depending on the tasks under consideration.

The relationships between intraindividual variability and performance were also examined by correlations. Mean latency and mean accuracy scores were correlated with across-trial and across-occasion ISDs. As can be seen in Table 9, across-trial variability was associated with latency scores both for data from the same task and across tasks. (The only exception was that variability on the CRT across trials was not associated with latencies on the VST). In other words, greater intraindividual variability on a given occasion was associated with greater response latencies.

Table 9 also shows that the across-occasion intraindividual variability was related to latencies, although these results were less consistent than for across-trial data. As with the across-trials data, variability on a task across occasions was related to latency scores for the same task. Variability on a particular task was also related to latencies on other tasks; coefficients ranged from -.06 (the only negative value) to .71. Across-occasion variability on the Stroop – dots and the Stroop – word yielded the strongest associations with across-task latencies. The CRT demonstrated the weakest relationships between

Table 9

Correlations Between Measures of Latency and Intraindividual Variability in Latencies

ISD Measure	Latency Measures						
	SRT	CRT	VST	Stroop – Dots	Stroop – Word	Stroop -Colour	Word
Across-Trials							
SRT	.87**	.74**	.50**	.70**	.64**	.68**	.67**
CRT	.71**	.77**	.22	.56**	.56**	.59**	.39*
VST	.56**	.69**	.92**	.58**	.68**	.58**	.63**
Word	.53**	.48**	.58**	.54**	.61**	.56**	.90**
Across-Occasions							
SRT	.71**	.66**	.21	.52**	.45*	.49**	.23
CRT	.34	.48**	-.06	.08	.13	.05	.04
VST	.39*	.27	.34	.38*	.24*	.48**	.23
Stroop – Dots	.70**	.60**	.43*	.66**	.54**	.67**	.41*
Stroop - Word	.53**	.61**	.55**	.43*	.54**	.39*	.40*
Stroop – Colour	.39*	.31	.29	.64**	.50**	.87**	.31
Word	.15	.21	.15	.10	.21	.20	.48**

* $p < .05$. ** $p < .01$.

intraindividual variability and latencies on other measures, with a mean correlation of .12.

Variability on each task was strongly and positively associated with latency performance on that task both within and across occasions. With respect to across-task comparisons, variability on a particular task was predictive of latencies on other tasks. This relationship generally held true for variability across occasions, but these relationships were weaker. In summary, an individual's level of variability on a particular occasion was related to their latencies, regardless of what task was examined. In contrast, the extent to which variability over time was predictive of latencies depended on the task.

Finally, correlational analyses between intraindividual variability and performance as defined by accuracy were calculated. Accuracy measures from the intake test battery (WAIS-III Block Design and Vocabulary) were included with the weekly measures. The results are presented in Table 10. With respect to intraindividual variability across-trials, most of the accuracy measures demonstrated negative relationships with variability. An exception was the Weekly Vocabulary task, which produced coefficients ranging from -.05 to .34. The WAIS-III Vocabulary task demonstrated weak relationships with intraindividual variability, with coefficients ranging from -.08 to .10. The negligible associations between vocabulary performance and intraindividual variability are not entirely surprising given that vocabulary skills are highly robust to disruptions in cognitive functioning. Correlations based on the other two accuracy measures ranged from -.41 to -.31, suggesting a decline in accuracy as intraindividual variability increases.

Table 10

Correlations Between Measures of Accuracy and Intraindividual Variability in Latencies

ISD Measure	Accuracy Measure			
	Word	Weekly Vocabulary	Block Design	WAIS-III Vocabulary
Across-Trials				
SRT	-.41	.01	-.40*	-.08
CRT	-.33	-.05	-.38*	-.05
VST	-.31	.34	-.31	.10
Word	-.33	.14	-.39*	-.03
Across-Occasions				
SRT	-.09	-.03	-.16	.02
CRT	-.10	.05	-.24	.08
VST	-.45*	-.06	-.43*	-.10
Stroop – dots	-.39*	.07	-.25	-.02
Stroop – word	-.21	.09	-.44*	-.07
Stroop – colour	-.17	.14	-.10	.15
Word	-.49**	-.09	-.25	-.18

* $p < .05$. ** $p < .01$.

Results based on across-occasion intraindividual variability demonstrated similar patterns. Accuracy on the vocabulary tasks was weakly related to intraindividual variability across occasions, with coefficients ranging from $-.18$ to $.15$. Accuracy on the other two tasks showed consistently negative associations with intraindividual variability over occasions. However, the magnitude of these relationships ranged from $.09$ to $-.49$, thus suggesting weaker associations than those observed with across-trials data. Within-task comparisons based on Word revealed that greater variability on this task was related to compromised accuracy on the same task. Overall, the relationships between accuracy and intraindividual variability were weaker than those between latency and intraindividual variability. However, the same pattern emerged in that performance was more closely related to variability within a given occasion than across multiple occasions.

To summarize, it appears that variability on a particular task persists over time and is predictive of performance on that task. Variability on a given task is also predictive of variability and performance on other tasks, but the extent of these relationships is weaker across occasions than within an occasion and varies considerably by task. Intraindividual variability on the Stroop – dots and Stroop – word tasks may be the best predictors of variability and performance on other tasks both within and across occasions. Conversely, intraindividual variability on the CRT may be a relatively weak predictor of variability and performance on other tasks. It should be emphasized that this evaluation of the CRT is relative to results based on the other measures; intraindividual variability on the CRT was predictive of variability and performance in many cases.

Correlations between predictors and intraindividual variability. Bivariate correlations were conducted in order to investigate the extent to which levels of biomarkers, affective, and somatic variables were related to levels of accuracy and speed of cognitive performance as well as intraindividual variability in cognitive performance. Table 11 presents the results of correlations between mean levels of predictor variables and accuracy in performance. Results were not consistent in that predictors were positively related to some measures of accuracy but negatively with others. Weekly Vocabulary accuracy demonstrated significant associations with four biomarkers but no affective/somatic predictors. The Word task differed from Weekly Vocabulary in that accuracy was more strongly related to affective/somatic variables rather than biomarkers. Overall, biomarkers demonstrated a greater relationship with accuracy in performance than affective/somatic predictors.

There were much stronger relationships between mean levels of predictors and latencies, as can be seen in Table 12. Similar to the correlations based on accuracy, associations were stronger between biomarkers and latencies than between affective/somatic variables and latencies. In particular, latencies were negatively related to hand grip strength (both right and left). Latencies were positively correlated with the length of time taken to complete finger dexterity tasks and walk a distance of 10 feet. Blood pressure was also positively correlated with latencies, although to a lesser extent than finger dexterity and walking. With respect to the affective/somatic predictors, the amount of pain during testing as well as the amount of pain during the preceding week were both strongly related to latencies. Higher levels of negative affect were associated with longer latencies, especially on the SRT and Word tasks.

Table 11

Correlations Between Mean Levels of Predictors and Accuracy Measures

Predictors	Accuracy Measures	
	Word	Weekly Vocabulary
Biomarkers		
Systolic	-.38	.34
Diastolic	-.55**	.25
Right grip	-.13	-.41*
Left grip	-.29	-.31
Turn	-.20	.02
Walk	-.20	.50**
Dominant dexterity	-.35	.40*
Nondominant dexterity	-.28	.41*
Affective/Somatic		
Current pain	-.48*	.02
Weekly pain	-.45*	.05
Stress	-.22	-.16
Positive affect	-.07	.31
Negative affect	-.56**	-.10

* $p < .05$. ** $p < .01$.

Table 12

Correlations Between Mean Levels of Predictors and Latency Measures

Predictors	Latency Measure						
	SRT	CRT	VST	Stroop – dots	Stroop – word	Stroop – colour	Word
Biomarkers							
Systolic	.21	.26	.42*	.28	.29	.12	.42*
Diastolic	.30	.29	.43*	.23	.23	.06	.42*
Right grip	-.54**	-.55**	-.38	-.66**	-.65**	-.60**	-.58**
Left grip	-.49*	-.46*	-.29	-.63**	-.56**	-.52**	-.47*
Turn	.02	.01	-.04	-.12	-.02	-.14	.22
Walk	.39*	.52**	.53**	.44*	.52**	.35	.66**
Dominant dexterity	.37	.43*	.35	.40*	.49*	.43*	.43*
Nondominant dexterity	.39	.46*	.35	.46*	.56**	.47*	.43*
Affective/Somatic							
Current pain	.54**	.40*	.38	.41*	.28	.35	.59**
Weekly pain	.53**	.48*	.51**	.48*	.37	.39*	.61**
Stress	.20	.06	-.03	.03	-.02	-.03	.30
Positive affect	.13	.23	.47*	.13	.38	.18	.14
Negative affect	.53**	.35	.13	.26	.15	.15	.49*

* $p < .05$. ** $p < .01$

Intraindividual variability in accuracy of performance was also correlated with mean levels of predictors. Results are presented in Table 13. Intraindividual variability on the Word task appeared to have somewhat stronger associations with biomarkers than affective/somatic predictors, a pattern that differed from what was observed with accuracy scores. Intraindividual variability on the Weekly Vocabulary task was strongly connected with pain, as well as negative affect. Biomarkers were also associated with intraindividual variability on Weekly Vocabulary, but to a lesser degree than when accuracy scores were examined.

Intraindividual variability in latency across trials demonstrated strong relationships with mean levels of predictors, as can be seen in Table 14. With respect to biomarkers, blood pressure, finger dexterity, and the walking task were positively correlated with variability on all tasks. Hand grip strength was negatively correlated with variability across all tasks. The only biomarker that did not demonstrate strong or consistent associations was the turning task. Within the affective/somatic category, pain and negative affect were correlated positively with all tasks, with coefficient values ranging from .06 to .72. Clearly, both types of predictors were related to intraindividual variability on each testing occasion.

Table 15 presents correlations between mean levels of predictors and intraindividual variability in latency across occasions. Finger dexterity was related to intraindividual variability in that longer completion times on the dexterity tasks were related to greater intraindividual variability across occasions. Weaker grip strengths were also associated with greater intraindividual variability, particularly on the Stroop – colour task. Intraindividual variability on the Stroop – dots task was related to pain and

Table 13

Correlations Between Mean Levels of Predictors and Intraindividual Variability in Accuracy

Predictors	ISD Measures	
	Word	Weekly Vocabulary
Biomarkers		
Systolic	.04	.04
Diastolic	.14	.27
Right grip	-.21	.05
Left grip	.04	.07
Turn	.46*	-.18
Walk	.36	-.31
Dominant dexterity	.40	-.27
Nondominant dexterity	.40*	-.32
Affective/Somatic		
Current pain	.04	.41*
Weekly pain	-.05	.31
Stress	.36	.21
Positive affect	-.18	-.03
Negative affect	.24	.54**

* $p < .05$. ** $p < .01$.

Table 14

Correlations Between Mean Levels of Predictors and Latency ISD Across-Trials

Predictors	ISD Measure			
	CRT	SRT	VST	Word
Biomarkers				
Systolic	.03	.40	.22	.39
Diastolic	.10	.49*	.25	.39
Right grip	-.23	-.52*	-.31	-.47*
Left grip	-.16	-.47*	-.21	-.37
Turn	.12	.07	-.03	.22
Walk	.33	.41*	.50**	.62**
Dominant dexterity	.43*	.42*	.38	.35
Nondominant dexterity	.47*	.43*	.39	.35
Affective/Somatic				
Current pain	.28	.72**	.28	.55**
Weekly pain	.26	.72**	.40*	.52**
Stress	.12	.18	-.06	.33
Positive affect	-.03	.11	.31	.03
Negative affect	.36	.66**	.06	.46*

* $p < .05$. ** $p < .01$

Table 15

Correlations Between Mean Levels of Predictors and Latency ISD Across-Occasion

Predictors	ISD Measure						
	CRT	SRT	VST	Word	Stroop – dots	Stroop – word	Stroop – colour
Biomarkers							
Systolic	-.05	.14	.02	.04	.30	.17	.02
Diastolic	-.04	.21	.08	.14	.43*	.29	-.07
Right grip	-.18	-.32	.16	-.21	-.27	-.37	-.61**
Left grip	-.03	-.27	.22	.04	-.15	-.32	-.54**
Turn	.36	.04	.00	.46*	-.19	-.11	-.25
Walk	.31	.23	.09	.36	-.15	.23	.12
Dominant dexterity	.38	.30	.22	.40	.28	.26	.32
Nondominant dexterity	.40*	.34	.23	.40*	.27	.23	.32
Affective/Somatic							
Current pain	-.09	.36	.12	.04	.59**	.22	.24
Weekly pain	-.18	.30	.10	-.05	.55**	.40*	.27
Stress	.14	.00	.11	.36	-.03	.06	-.23
Positive affect	-.14	-.04	.18	-.18	.05	.36	.10
Negative affect	.09	.32	.23	.24	.45*	.30	-.03

* $p < .05$. ** $p < .01$

negative affect. These relationships occurred with most of the other tasks, but to a lesser extent. Neither class of predictor demonstrated clearly stronger relationships with intraindividual variability.

Group Classification

A question of interest was whether or not level of performance and intraindividual variability could differentiate between groups and, if so, whether one type of variable could predict group membership independently. This is an important issue because reliable markers of CFS, whether biological or cognitive, remain largely unidentified. In order to explore this matter, discriminant function and linear regression analyses were performed to predict group membership using various combinations of data.

For the CRT, VST, and Word tasks the analyses included variables based on average accuracy, average latency, across-trials latency ISD, across-occasions latency ISD, and across-occasions accuracy ISD. Variability information [$F(2,27) = 18.76, p < .001, \text{Wilks' lambda} = .50$] and performance variables [$F(1,28) = 13.51, p < .001, \text{Wilks' lambda} = .61$] from the SRT differentiated between the CFS and healthy groups. Combining the two types of information also distinguished between the two groups, $F(3,26) = 20.03, p < .001, \text{Wilks' lambda} = .47$. The variability data contributed independently to predicting group membership, $F(2,26) = 3.94, p < .05$, change in $R^2 = .14$. Classification rates based on levels of performance data (accuracy and latency) were 57.1% for CFS patients and 100% for healthy persons, resulting in an overall rate of 80%. When variability data were combined with performance information, the

classification rate for the CFS group improved to 71.4% and the rate for the healthy group remained the same, producing an overall rate of 86.7%.

Similarly, variability data based on the CRT were significant predictors of group membership, $F(3,26) = 20.67$, $p < .001$, Wilks' lambda = .46, as were performance data, $F(2,27) = 30.43$, $p < .001$, Wilk's lambda = .32. The performance and variability data in combination were also significant predictors of group membership, $F(5,24) = 38.46$, $p < .001$, Wilk's lambda = .22. Regression analyses confirmed that the variability data were independent contributors to the prediction of group membership, $F(3,24) = 3.71$, $p < .05$, change in $R^2 = .10$, as were the performance data, $F(2,24) = 12.86$, $p < .001$, change in $R^2 = .24$. When group membership was predicted based on variability data alone, 92.9% of CFS patients were classified correctly and 87.5% of healthy participants were classified correctly. These classification rates were identical when performance information was used to predict group membership. When combined, variability and performance data resulted in a 100% correct classification rate for both groups. The overall rate of correct classification was 90% when performance alone was used to predict group membership, and the rate was identical when variability was the basis of predicting group membership.

On the VST, performance variables emerged as significant predictors of group membership, $F(2,27) = 28.12$, $p < .001$, Wilks' lambda = .35. Variability data also differentiated between the CFS and healthy groups, $F(3,26) = 15.97$, $p < .01$, Wilks' lambda = .55, as did the combination of performance and variability information, $F(5,24) = 29.21$, $p < .001$, Wilks' lambda = .32. Level of performance contributed independently to differentiating the groups, $F(2,24) = 8.65$, $p < .01$, changed in $R^2 = .23$. Variability

information produced a correct classification rate of 85.7% for the CFS group and 75% for the healthy group; the overall rate was 80%. These rates improved to 92.9% and 93.8%, respectively, when performance predictors were used in combination with the variability data to predict group membership. Overall, 93.3% of all participants were correctly classified using both performance and variability data.

On the Stroop tasks, group membership was predicted using average accuracy, average latency, across-occasions latency ISD, and across-occasion accuracy ISD. Variability¹ on the Stroop – dots task differentiated between the two groups, $F(1,28) = 7.18, p < .01$, Wilks' lambda = .77, as did performance, $F(2, 27) = 16.23, p < .001$, Wilks' lambda = .55. Group membership was also predicted by the combination of performance and variability information, $F(3,26) = 16.59, p < .01$, Wilks' lambda = .54. Performance data were independent contributors in predicting group membership, $F(2, 26) = 5.72, p < .01$, change in $R^2 = .24$. Adding performance data to variability data improved classification rates from 50% for the CFS group (based on variability data only) to 78.6%. Performance data did not enhance identification of healthy participants, as a total of 87.5% of healthy individuals were correctly classified using both variability data alone and a combination of variability and performance information. The overall rate of correct classification improved from 70% to 83.3%.

On the Stroop – word task, both variability¹ [$F(1,28) = 6.09, p < .05$, Wilks' lambda = .80] and performance [$F(2,27) = 18.14, p < .001$, Wilks' lambda = .51] predicted group membership, and their combination did as well: $F(3,26) = 16.59, p < .01$, Wilks' lambda = .54. Performance was an independent contributor in the prediction of group membership, $F(2,26) = 7.81, p < .01$, change in $R^2 = .30$. Without the contribution

of performance data, variability information yielded a correct classification rate of 64.3% for the CFS group and 81.3% for the healthy group, resulting in an overall rate of 73.3%. When performance data was included in the prediction of group membership, 78.6% of CFS patients were correctly identified, 87.5% of healthy participants were classified correctly, and 83.3% of all participants were correctly identified.

Variability [$F(2,27) = 16.34, p < .001, \text{Wilks' lambda} = .55$] and performance [$F(2,27) = 9.83, p < .01, \text{Wilks' lambda} = .70$] information from the Stroop – colour task differentiated the CFS and healthy groups, and so did the combination of these two types of predictors, $F(4,25) = 22.36, p < .001, \text{Wilks' lambda} = .42$. Variability proved to be an independent contributor to predicting group membership, $F(2,25) = 8.03, p < .01$, change in $R^2 = .27$. Performance data also contributed uniquely to predicting group membership, $F(2,26) = 5.72, p < .01$, change in $R^2 = .24$. Using variability information alone, 71.4% of CFS patients were correctly classified and 93.8% of healthy individuals were appropriately classified. The overall rate of correct classification based on variability data was 83.3%. Performance variables were less accurate than variability information in classifying CFS patients, producing a rate of 57.1%. Performance data were identical to variability data in the rate of correctly identifying healthy individuals, and the overall rate of correct classification for performance data was 76.7%. Combining variability and performance data led to an improved classification rate for the healthy individuals – 100%. Combined predictors successfully classified 71.4% of CFS patients, identical to what was found using variability data.

Group membership was predicted by both the variability [$F(3,26) = 25.33, p < .001, \text{Wilks' lambda} = .39$] and performance [$F(2,27) = 17.38, p < .001, \text{Wilks' lambda} =$

.53] information from the Word task. The combined information also distinguished between the CFS and healthy groups, $F(5,24) = 35.02$, $p < .001$, Wilks' lambda = .25. Variability data made independent contributions to predicting group membership, $F(3,24) = 8.59$, $p < .001$, change in $R^2 = .27$. Unique contributions were also provided by performance variables, $F(2,24) = 6.22$, $p < .01$, change in $R^2 = .13$. Independently, variability correctly classified 85.7% of CFS patients and 87.5% of healthy participants, with an overall rate of 86.7%. Performance data produced lower rates: 78.6% for the CFS group, 81.3% for the healthy group, and 80% overall. In combination, the two types of variables correctly identified 92.9% of CFS patients, 93.8% of healthy individuals, and 93.3% of all participants.

Finally, accuracy scores and across-occasions accuracy ISD for the Weekly Vocabulary task were used to predict group membership. Performance distinguished between the two groups, $F(1,28) = 3.94$, $p < .05$, Wilks' lambda = .87, but variability did not. The combination of performance and variability predictors predicted group membership, $F(2,27) = 7.64$, $p < .05$, Wilks' lambda = .75. Performance made independent contributions to predicting group membership, $F(1,27) = 7.55$, $p < .05$, change in $R^2 = .21$. Variability was a poor predictor of group membership, correctly classifying 42.9% of CFS participants and yielding a better rate for the healthy group – 75%. The overall rate of correctly classified participants was 60%. Combining performance data with variability data led to an improved classification rate for the CFS group, 64.3% but no change for the healthy group. The overall rate of correct classification increased to 70% when data were combined.

DISCUSSION

The present findings both partly confirmed the hypotheses underlying the study and yielded some surprises. To summarize, perhaps the most readily interpretable findings are that individuals with CFS were consistently slower than healthy individuals on reaction time tasks, and that the two groups did not differ in the accuracy of their performance. Greater intraindividual variability in latencies was observed within the CFS group than the healthy group, but the magnitude of these group differences was dependent on the time frame used. The CFS group demonstrated greater intraindividual variability than the healthy group on SRT, CRT, VST, and Word when within-occasion data were analyzed, but significant group differences on these tasks were absent when across-occasion data were considered. The CFS group demonstrated greater intraindividual variability than the control group on two of the three Stroop tasks using the across-occasion data. With respect to intraindividual variability in accuracy, there were minimal group differences with CFS patients demonstrating greater variability than healthy persons only on the Weekly Vocabulary task. The magnitude of intraindividual variability in latencies within the CFS group varied by task but was not necessarily related to task complexity. On several tasks, intraindividual variability emerged as a significant predictor of group membership, either independently or in combination with actual performance data. Major findings will now be discussed in more detail.

Levels of Performance

As predicted, CFS patients demonstrated consistently slower reaction times than healthy individuals. This is in keeping with previous findings (Grafman et al., 1993; Marshall et al., 1997; Scheffers et al., 1992; Smith et al., 1993; Smith et al., 1999). The

tasks in the present study varied in terms of complexity and the cognitive processes they measured, suggesting that CFS patients may experience a global slowing of cognitive processing speed. Similar findings can be found in the aging and cognitive performance literature, with older adults consistently demonstrating slower reaction time performance than younger adults (e.g., Grewal, 1988; Rubichi, Neri, & Nicoletti, 1999; Stelmach, Goggin, & Amrhein, 1988). In terms of potential causes of increased latencies, it has been proposed that longer latencies among older adults are due primarily to slowed perceptual processing rather than impaired motor functions (Salthouse, 1996). Marshall et al. (1997) have suggested that slowed performance in individuals with CFS reflects both cognitive and motoric factors. The extent to which speed of perceptual processing and motor functioning contributed to the longer latencies observed in the CFS group is unclear, but the importance of processing speed will be addressed shortly.

The overall absence of group differences with respect to accuracy of performance was consistent with some previous findings based on CFS patients (Grafman et al., 1993; Michiels et al., 1998). It appears that the cognitive difficulties encountered by CFS patients are more closely related to how quickly information can be processed and responses executed rather than accessing acquired knowledge or making accurate judgments. The fact that group differences were observed on latencies but not accuracy highlights the need for specificity in explaining cognitive performance in CFS patients, as broad conclusions do not account for variability in performance across conditions.

Group Differences in Intraindividual Variability

With respect to group differences in intraindividual variability, there was clearly greater intraindividual variability in latencies among the CFS group than the healthy

group on each occasion, but these differences were absent when across-occasion data were used. (This was not necessarily true of the Stroop, which yielded only across-occasion data and no across-trials data. The CFS group demonstrated greater intraindividual variability than the control group on the Stroop – dots and Stroop - word tasks). The discrepancies between the findings based on different time frames illustrates the importance of analysing and interpreting intraindividual variability within a temporal context. In the present study, the shorter time frame of single occasions better represents the magnitude of intraindividual variability in CFS patients. If only across-occasions data had been analysed, the considerable fluctuations in CFS patients' performance would have been obscured. Conversely, using only across-trials data could have led to the erroneous conclusion that overall intraindividual variability remains constant over long periods of time in CFS patients.

Group differences in intraindividual variability in accuracy were less pronounced than when latency was used as a performance marker. This finding is not very surprising considering that CFS patients are consistently slower than healthy persons (Grafman et al., 1993; Scheffers, Johnson, Grafman, Dale, & Straus, 1992; Marshall, Forstot, Callies, Peterson, & Schenck, 1997; Smith, Behan, Bell, Millar, & Bakheit, 1993; Smith et al., 1999) but group differences do not always occur on measures of accuracy (Grafman et al., 1993; Michiels et al., 1998). This is consistent with recent work in the field of aging and intraindividual variability in cognitive performance that has shown that speed of performance and variability reflect age-group differences to a greater extent than accuracy measures (Anstey, 1999; Hultsch et al., 2000). The cognitive processes involved primarily in accuracy performance appear to be less vulnerable to

intraindividual variability among CFS patients than those involved mainly in latency performance.

The fact that results varied depending on how performance was defined and measured lends support to the idea that intraindividual variability is a multifaceted phenomenon. Shammi, Bosman, and Stuss (1998) found that intraindividual variability among older adults varied across a range of cognitive tasks, and that the across-task inconsistencies were due to the multidimensional nature of intraindividual variability. Similarly, the different patterns of results observed in accuracy and latency data in the present study suggest that the magnitude of intraindividual variability varies across aspects of performance. The present results also varied across tasks, as will now be discussed.

Processing Speed and Task Difficulty

The failure to find greater intraindividual variability in latencies on relatively complex tasks may be understood by considering the role of processing speed. In this study, the SRT was considered to be the simplest task, with the other tasks requiring cognitive processes beyond reacting to a single stimulus. When considering performance across occasions, persons with CFS demonstrated greater variability on the SRT than on the CRT and VST. Similarly, the Stroop – dots task, which is the simplest Stroop task, yielded the greatest magnitude of intraindividual variability when compared to the other two Stroop tasks.

Marshall et al. (1997) found similar results when they investigated CFS patients' latencies on the SRT, CRT, and a battery of other neuropsychological tests. They found that the patients' SRT and CRT latencies were comparable. Moreover, they found that

CFS patients had more difficulty with relatively simple tasks such as the SRT and CRT when compared with more demanding tasks such as a structured memory test. The authors suggested that higher processing speed demands are what differentiates tasks on which CFS patients have relative difficulty. This hypothesis is consistent with the present results. As noted above, the highest level of intraindividual variability in the CFS group occurred on the Stroop – dots task. This task is arguably the most “pure” measure of processing speed out of the three Stroop tasks, as it does not involve competing or distracting stimuli. Interestingly, the least amount of intraindividual variability was observed on the Stroop – colours task, which presents considerable cognitive demands in addition to processing speed. With respect to the other latency measures, SRT is the purest measure of processing speed as the other tasks encompass additional demands such as stimulus identification. Thus, it appears that the more central processing speed is to a task, the less stable is performance among persons with CFS.

In their review paper, Tiersky et al. (1997) concluded that CFS patients’ performance on tasks of attention and information processing was poorer than that of healthy persons but only on relatively complex tasks. They attributed these group differences to processing speed, identifying slowed processing speed and/or efficiency as central elements in cognitive difficulties. Once again, it would seem that processing speed demands rather than complexity per se may be the key to explaining cognitive performance deficits among CFS patients.

A different pattern of results was obtained when intraindividual variability in accuracy was examined. The groups differed significantly on the accuracy measure that was relatively complex (Weekly Vocabulary), unlike what was found on the latency

measures. These two different forms of performance, accuracy and latencies, appear to vary in their associations with processing speed demands and task difficulty, with accuracy co-varying more closely with task complexity and latencies being more strongly related to processing speed demands. Accuracy in performance was at ceiling levels in both groups across most tasks, suggesting that the effects of task difficulty are not highly robust, and that the relationships between intraindividual variability in latencies and processing speed requirements may be stronger than the associations between intraindividual variability in accuracy and task complexity.

However, the two tasks that produced variability in accuracy differed from those that resulted in ceiling-level performances. Specifically, the instructions for the two tasks that showed variability in accuracy did not direct participants to respond as quickly as possible, whereas the instructions for the other accuracy measures did emphasize the need for rapid performance. Processing speed demands on the latter tasks may have somehow eliminated the effect of task complexity. It is not clear why the demand for rapid performance is associated with consistently accurate performance, but this finding illustrates that the effects of task complexity and processing speed demands are not cumulative with respect to intraindividual variability in accuracy. The same may be said of intraindividual variability in latencies, as greater fluctuations would have occurred on relatively difficult tasks if task complexity and speed demands combined additively to affect performance.

Intraindividual variability in cognitive performance may be a result of fluctuations or relatively stable declines in processing speed abilities. Alternatively, intraindividual variability in cognitive processes that accompany processing speed

performance may cause disruptions in processing speed. The causal relationships (if any) between processing speed performance and intraindividual variability in cognitive performance remain unknown, but the present data suggest co-variation between these two variables.

Another issue to be considered when examining why CFS patients did not demonstrate greater intraindividual variability in latencies on relatively difficult tasks is the meaning of “difficult.” In the present study, complex tasks were defined as those that posed relatively greater cognitive challenges by presenting distracting information or evoking higher-order cognitive skills (e.g., the Word memory task vs. SRT). It is possible that the tasks in the present study did not vary sufficiently in complexity to produce the expected across-task effects. However, the Stroop – colour task is generally regarded as a significantly more demanding, or complex, task than the other two Stroop tasks. If intraindividual variability in CFS patients was related to the degree of complexity of cognitive tasks, this association should have emerged on the three Stroop tasks. Instead, the findings were opposite to what was predicted. It should be emphasized that these findings are based on intraindividual variability and not actual performance. Intraindividual variability in CFS patients may be more sensitive to fairly basic cognitive processes such as processing speed than the higher-order abilities required by the Stroop – colour task, such as focused attention and inhibition of responses.

Intraindividual Variability in Latencies and Levels of Performance

Greater intraindividual variability in latencies was associated with longer

latencies, although the magnitude of these relationships varied with time frames. These relationships were strongest when within-occasion, or across-trials, variability data were considered. Of particular interest was the fact that, with only one exception, these relationships were found across tasks as well as within each individual task. This suggests that intraindividual variability is to some extent a function of processes involved in a variety of cognitive operations as opposed to highly specialized abilities. If intraindividual variability was primarily determined by task-specific characteristics, such as the extent of stimulus differentiation required by the task, then relationships between reaction time performance and intraindividual variability would have been strong within-tasks but relatively weak across tasks. It appears that, within a single testing session, the degree of intraindividual variability that a person experiences is strongly related to relatively global cognitive factors such as processing speed.

Intraindividual variability over multiple testing sessions was also predictive of within-task latencies. However, intraindividual variability across occasions was not strongly related to across-task latencies in general. One possible explanation for this is that intraindividual variability as calculated over a span of time that reflects the cumulative effects of or associations with a variety of factors. For example, if intraindividual variability is related to variables such as physical pain and mood, then perhaps variability as measured over a span of weeks reflects these influences to a greater extent than it does on a single occasion. Intraindividual variability may be strongly associated with a global cognitive ability (e.g., processing speed) on a single occasion, but over a larger time frame it may represent the relative impact of or co-variation with a variety of factors. It would be reasonable to expect that, as the set of possible co-variates

of intraindividual variability increases, the relative associations with different measures of performance would become increasingly diverse. In other words, factors such as the experience of pain could be related by varying degrees with performance on different tasks, resulting in a cumulative effect over time whereby across-task relationships would be weakened. Across-task associations could be furthered weakened as a function of the number of co-variables playing a role in performance over time (i.e., greater numbers of co-variables would likely further weaken across-task relationships).

The associations between intraindividual variability and cognitive abilities were generally weaker when accuracy was used as a marker of performance, but the general pattern indicated that greater intraindividual variability was associated with poorer accuracy. This pattern was least evident on the WAIS-III Vocabulary and Weekly Vocabulary tasks, and most evident on the WAIS-III Block Design task. An obvious difference between these tasks is that the first two focus on the recall and processing of acquired verbal knowledge, whereas the latter requires rapid processing of visual, non-verbal information. Vocabulary skills and other forms of crystallized intelligence are not highly sensitive to relatively minor shifts in neurological or cognitive functioning. However, it appears that more fluid cognitive abilities may be relatively vulnerable to, or indicative of, fluctuations in cognitive performance.

Is Intraindividual Variability a Stable Characteristic in CFS?

Although straightforward patterns were evident in the results, findings appeared to vary along two dimensions: task characteristics and time frames. For example, the CFS group demonstrated greater intraindividual variability than the healthy group when across-trials data were analysed, but these group differences were eliminated when

performance across all occasions was used as a basis of comparison. Similarly, the effects of task characteristics were apparent in findings such as the observed relationships between intraindividual variability and accuracy on a non-verbal task and the absence of such relationships for verbal tasks.

Intraindividual variability was stable within the CFS group in that variability on a given task was consistent across occasions, and variability within a session was consistent across tasks. These findings strongly suggest that intraindividual variability is not a random, uninformative measure of functioning. Furthermore, intraindividual variability was found to be associated with performance as defined by latencies. Intraindividual variability may serve as a reliable marker of both performance and variability at different points, or across a span, of time.

The stability of intraindividual variability is somewhat weaker when defined as across-task stability over time. Variability on a particular task is not necessarily predictive of variability on different tasks over time. In addition to the possible effects of shifts in state variables, fluctuations in intraindividual variability across time and across cognitive tasks may be linked to the heterogeneity of CFS. There may be considerable diversity in the experience of CFS not only between patients, but within patients as well. There are several non-empirical accounts in the clinical literature describing how the severity and type of CFS symptoms fluctuate over time, with some patients going through episodic remissions, others experiencing gradual worsening of symptoms, and others attaining full recovery. It seems plausible that fluctuations in CFS symptoms may be related to variations in intraindividual variability in cognitive performance. It may be that relatively severe physiological symptoms, possibly in conjunction with negative

changes in affect, coincide with increased intraindividual variability in cognitive performance.

One logical conclusion that follows from the present results is that intraindividual variability in CFS patients is not a result of a “common cause” in the form of relatively stable neurological dysfunction. If intraindividual variability was related to permanent and relatively stable neurological dysfunction it would be expected that results would show consistency over time, which was not the case. This is of particular relevance to the CFS group because it suggests that, as measured over the span of several weeks, CFS patients are not characterized by stable neurological deficits. If CFS patients experienced stable or slowly progressive neurobiological abnormalities, it would be expected that intraindividual variability would remain largely constant over time, as has been found with dementia patients (Hultsch et al., 2000). The absence of such consistency is more compatible with short-term, reversible neurocognitive weaknesses rather than a unitary relationship between actual organic neurological deterioration and increased variability. As discussed earlier, neurological studies of CFS patients have found some neurophysiological abnormalities, but these findings vary by patient and do not indicate prominent neurological dysfunctions.

The inconsistency of intraindividual variability over time suggests that it reflects short-term fluctuations in areas of functioning other than neurocognitive processes, at least to some degree. This possibility is supported by the findings that non-neurological factors were found to be strongly related to intraindividual variability. In particular, negative affect and self-reported levels of pain, both at the time of testing and in the preceding week, were found to be associated with intraindividual variability. Across-

trials intraindividual variability was more strongly related to these variables than across-occasions variability suggesting that their influence (if any) on variability is of a short-term nature. That is, their effects were not cumulative over time. Thus, “state” variables that reflect highly mutable areas of functioning are predictive of intraindividual variability. Furthermore, the magnitudes of their relationships with intraindividual variability varied by task. It is not surprising, then, that intraindividual variability on one occasion is not necessarily predictive of intraindividual variability on another occasion.

Biomarkers that reflect central nervous system functioning were also found to be strongly related to intraindividual variability. Biomarkers that are subject to fluctuations (e.g., blood pressure) demonstrated stronger relationships with intraindividual variability than more stable biomarkers (e.g., the ability to walk in a circle). These findings lend credence to the idea that intraindividual variability is a multidimensional phenomenon, co-varying with both physiological and subjective factors.

The relative importance of each type of factor to predicting intraindividual variability may depend on the degree of neurological dysfunction occurring. It is possible that, as the degree of neurological dysfunction increases, the predictive power of non-physical factors decreases. This could be due to a restriction in range, in that factors such as mood or stress might not vary a great deal in persons with serious neurological impairments. Alternatively, these types of factors might vary considerably but have relatively weak relationships with intraindividual variability when compared with the encompassing nature of neurological deterioration. In CFS patients, who do not have prominent neurological difficulties, neither type of predictor emerges as a clearly stronger co-variate of intraindividual variability.

Implications

As discussed above, the effects of intraindividual variability may be less evident on tasks that draw upon crystallized intelligence as opposed to more fluid cognitive abilities. The degree to which a task requires factual knowledge vs. novel problem-solving may serve as a valuable dimension in evaluating intraindividual variability in CFS patients. For example, it would be possible to develop models predicting intraindividual variability based on cognitive performance, with fluid reasoning tasks presumably acting as stronger predictors than tasks based on factual knowledge. Also, subgroups within CFS populations may differ with respect to the extent each type of task reflects intraindividual variability. More severely impaired patients might demonstrate stronger relationships between crystallized intelligence and intraindividual variability.

CFS patients demonstrated slower reaction time performance than healthy persons. This pattern of results has been found in numerous studies and seems to reflect reliable group differences. The finding that persons with CFS are slower than healthy individuals is informative, but a more accurate picture of functioning within CFS could be obtained via normative data specific to this population. That is, in order to determine the magnitude of speed deficits it would be useful to compare a CFS patient's reaction time performance with overall performance in the group. The advantages of using CFS-specific normative data are illustrated if we consider two hypothetical patients, both of whom demonstrate longer latency times than those of healthy persons. Relative to the CFS population, one individual could score significantly higher than the group mean, indicating relatively minor impairments, whereas the other might manifest significant impairments by scoring much lower than the group mean. The purpose of this study was

not to examine within-group differences, but the emergence of between-group and within-individual differences in performance suggests that variability with the CFS population may prove to be an informative topic of research.

The finding that CFS patients are more variable than controls on a given occasion supports the contention that single-occasion measurement may not accurately reflect CFS patients' true cognitive abilities. The correlational analyses demonstrated that greater intraindividual variability on a particular task was associated with longer reaction times (with the exception of across-occasion data from the VST) and poorer accuracy on the same task. A person's cognitive performance varies with their level of intraindividual variability within a testing occasion, indicating that testing results at least partly reflect the degree of intraindividual variability. Following from this, it is evident that testing an individual at a time when he/she is experiencing considerable short-term fluctuations in cognitive performance would not produce accurate performance results. It would seem that sampling the cognitive functioning of CFS patients' cognitive performance over different points in time would provide more accurate estimates of true abilities than extrapolating from single-occasion measurements.

Related to the above, significant intraindividual variability among CFS patients may help explain why their subjective reports of cognitive difficulties often exceed objective evidence obtained in research studies. One possible explanation is that single-occasion testing sessions may coincide with times when intraindividual variability is relatively minimal, resulting in no observable cognitive difficulties. This may be especially likely if intraindividual variability is related to factors such as mood and physical well-being, as CFS patients are likely to refrain from taxing activities when they

feel unwell. The present study supports the possibility that CFS patients experience a greater range of fluctuations in cognitive functioning than healthy persons, underscoring the need to accurately measure the range of functioning rather than relying on a single estimate.

Other factors may interact with intraindividual variability to contribute to the discrepancy between subjective and objective measures of cognitive difficulties. CFS patients are able to accurately evaluate their cognitive performance when given appropriate feedback (Wearden & Appleby, 1997). This does not preclude the possibility that there is a selective perceptual bias in CFS wherein individuals attend to information that supports their perceptions of cognitive difficulties and discount evidence that negates cognitive deficits. In the absence of direct feedback, persons with CFS may overemphasize indications of cognitive problems. Such a bias could be exacerbated by intraindividual variability in cognitive performance, with greater variability interpreted by an individual as stable cognitive deficits. Regardless of whether any consistent biases in judging cognitive abilities exist, it seems likely that perceptions of performance would co-vary with intraindividual variability, especially as actual performance is a covariate.

Intraindividual variability was a stable characteristic of the CFS group in general, but task characteristics and time frames did appear to be related to the magnitude and stability of variability. This pattern of results is not surprising considering the wide range of results that have been obtained by measuring cognitive performance in CFS patients (see Tiersky et al., 1997; Wearden, & Appleby, 1996; 1997). Some trends have been identified in the literature, but results vary widely across testing situations and generalizations are very limited. Even within one study, there are often discrepancies

such as impaired performance on one measure but unaffected performance on another measure of the same cognitive ability. Considering that intraindividual variability was consistently associated with performance both within and across tasks, it would appear that intraindividual variability may be a fairly consistent indicator of performance when compared to individual cognitive tasks. In other words, the assessment of intraindividual variability may have greater generalizability than the results of one, or even multiple, specific tasks.

It was also evident that intraindividual variability co-varied with physiological functioning as well as perceived pain and negative mood states. While the relationships between these factors and intraindividual variability may not be causal, their existence illustrates that a person's short-term functioning in a variety of areas is somehow related to intraindividual variability and, by extension, to levels of performance. The most obvious interpretation of these findings is that testing a CFS patient on an occasion when difficulties in functioning, either subjective or physiological, exist could result in an inaccurate estimate of potential performance. Testing results would be accurate for that point in time, but could significantly underestimate what the individual might achieve on another occasion.

Much of the extant work on intraindividual variability in cognitive performance has focused on older adults and persons with brain injuries. It appears that the utility of intraindividual variability as a meaningful indicator of functioning also extends to persons with CFS. This is of interest because intraindividual variability may be a useful and meaningful marker of performance in a variety of populations, not just those for whom aging or neurological damage is a central issue. Hultsch et al. (2000) found that

intraindividual variability was not greater among arthritis patients than healthy persons, suggesting that general somatic or non-neurological physical problems may not be associated with increased intraindividual variability. It is more likely that populations who experience cognitive disturbances similar to or more severe than those reported by CFS patients may be particularly susceptible to intraindividual variability. For example, intraindividual variability may be a prominent feature of illnesses such as multiple sclerosis.

One final implication of the present results is that intraindividual variability may help distinguish persons with CFS from those without the disorder. The predictive power of intraindividual variability alone is not sufficient to identify CFS patients, but when used in conjunction with other assessment procedures intraindividual variability could provide useful information. This potential use of intraindividual variability is of interest given that definitive markers of CFS remain elusive and there is no typical cognitive profile of CFS patients. Also, considering the heterogeneity of CFS, it is possible that intraindividual variability could be used with other data to differentiate subgroups of CFS patients.

Limitations and Directions for Future Research

There are limitations in the present study that should be remedied in future studies. Although the time frame of sampling performance on ten occasions provided a reasonably large sample of occasions, longer time frames with more testing occasions would provide information about intraindividual variability as it occurs over longer time spans. Longer time frames could provide information about intraindividual variability as a “trait” variable rather than a “state” variable (e.g., whether or not individuals

demonstrate long-term consistency in their levels of intraindividual variability). A longer time frame would also allow for determining whether or not there are cyclical patterns in intraindividual variation. This would be of particular interest with respect to performance across different seasons of the year. Several of the participants in the CFS group mentioned that they experience seasonal patterns in their symptoms, with most people reporting increased difficulties during the winter.

Another limitation related to the time frame of sampling is that diurnal variation was not addressed. Participants were tested across a wide range of times, ranging from approximately 7:30 AM to 11:00 PM but potential effects of time of testing were not examined due to the small sample size. Considering that functioning in many domains does not remain constant across the day (e.g., some individuals are most alert during morning hours, others are most alert during the evening), it is likely that the degree of intraindividual variability does not remain constant across a 24-hour cycle. Of particular interest is the fact that no CFS patients wanted to be tested after approximately 7:00 PM due to an increase in fatigue in the evening. A larger sample size would allow for an investigation of the extent to which time of day is related to both cognitive performance and intraindividual variability in performance.

Another issue that should be addressed in future research is the degree of subjective impairment reported by participants. The participants in the CFS group were all volunteers, and there was very likely a self-selection bias in that only individuals at relatively high levels of functioning elected to participate. We did not include any measures of symptom frequency or severity, but it would be of interest to include such measures in order to determine: (1) if self-selected samples are homogeneous in terms of

their experience of CFS, and (2) whether or not perceptions of physical and cognitive impairment are related to cognitive performance and intraindividual variability..

The role of task characteristics in intraindividual variability also merits more detailed investigation. With respect to information processing tasks, more refined comparisons of task features such as processing speed demands, complexity of response options, and complexity of stimulus discrimination would help illuminate what cognitive processes are characterized by intraindividual variability. In a similar vein, interactions between processing speed demands, task complexity, and how performance is defined (latencies vs. accuracy) could prove to be informative. Regarding the definition of performance, other measures such as the ability to shift a cognitive set or generate multiple solutions to a problem have not been investigated in relation to intraindividual variability in cognitive performance. It would also be of considerable interest to compare intraindividual variability in different cognitive domains, such as acquired knowledge, fluid reasoning, and memory. Intraindividual variability may prove to be more closely related to particular types of cognitive abilities. Finally, difference modalities of information processing (i.e., visual or auditory information) should be compared to examine potential modality differences in the relationships between intraindividual variability in cognitive performance and actual performance.

It appears that intraindividual variability may be a multifaceted phenomenon that reflects functioning in a variety of areas including both neurobiological and environmental factors. Transient, or state variables, may be particularly relevant to the understanding and prediction of intraindividual variability among CFS patients. Toward

this end, future investigations should address the relationships between intraindividual variability, cognitive performance, and environmental factors.

Intraindividual variability predicted reaction time performance, demonstrated consistency across cognitive domains on single occasions, and stability within domains across occasions. The results indicate that intraindividual variability is a meaningful indicator of cognitive performance and is not merely a result of measurement error. This is consistent with other recent research that has also found that intraindividual variability is a significant component of cognitive functioning within older adults (Anstey, 1999; Hultsch et al., 2000; Li et al., 2000; Shammi et al., 1998). Inconsistency in performance may be particularly relevant for CFS patients not only because it indicates the level of cognitive performance, but also because it could potentially serve as a marker of CFS. CFS patients demonstrated greater intraindividual variability than healthy persons; theoretically, this type of variability could be used in conjunction with other information to identify persons with CFS. In summary, intraindividual variability is a relevant concept for understanding cognitive functioning in CFS patients and merits further study.

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Footnote

¹ Across-occasions latency ISD were omitted from the discriminant function analysis using variability data from the Stroop – dots task. The statistical package SPSS removes variables that do not meet tolerance criteria (i.e., those that do not demonstrate independence from other predictor variables) as they are redundant.

Appendix A

International Chronic Fatigue Syndrome Study Group Criteria

Inclusion Criteria

1. Clinically evaluated, medically unexplained fatigue of at least six months' duration that is:
 - of new onset (not lifelong)
 - not the result of ongoing exertion
 - not substantially alleviated by rest
 - accompanied by a substantial reduction in previous level of activity

2. The occurrence of four or more of the following symptoms:
 - impairment in short-term memory or concentration
 - sore throat
 - tender lymph nodes
 - muscle pain
 - multi-joint pain without swelling or redness
 - headaches
 - unrefreshing sleep
 - post-exertional malaise lasting more than 24 hours

Exclusion Criteria

- Active, unresolved or suspected disease
- Psychotic, melancholic, or bipolar depression (but not uncomplicated major depression)
- Psychotic disorders
- Dementia
- Anorexia or bulimia nervosa
- Alcohol or other substance misuse
- Severe obesity