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Concussion Does Not Impact Intraindividual Response Time Variability

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This investigation examined the effect of concussion on intraindividual variability in 5 processing speed tasks. Forty-four adults, including 22 concussed and 22 healthy age- and gender-matched participants, completed the Headminder Concussion Resolution Index (D. M. Erlanger, D. J. Feldman, K. C. Kutner, & M. McCrea, 2001) twice. The test consists of a series of tasks including 25 trials of simple response time task, 70 trials of cued response time task (CuRT), 60 trials each for 2 visual recognition tasks, and 30 trials of symbol scanning task. Concussed participants completed a preinjury baseline assessment and were retested within 48 hours of injury diagnosis. The nonconcussed participants were retested 45 days after initial assessment. Average response time (RT), standard deviation, and response accuracy were calculated for each individual. Overall, concussed individuals had increased RTs across all tasks and were less accurate in the CuRT. RT variability for all tasks was elevated in concussed individuals, but controlling for mean RT at follow-up eliminated group differences. These findings indicate that response-time-variability increases in concussed individuals are proportional to processing-time increases. As such, RT variability is not a unique identifier of cognitive dysfunction following concussion. These results highlight that transient brain injury has significantly different neurobiological consequences than chronic conditions have.

Keywords: response time, response variability, mild traumatic brain injury, Concussion Resolution Index

Approximately 1.5 million traumatic brain injuries occur in the United States on an annual basis (Sosin, Sniezek, & Thurman, 1991) with a total direct and indirect cost estimated at over $60 billion (Finkelstein, Corso, & Miller, 2006). More than 75% of these injuries are considered mild traumatic brain injuries, or concussions, that largely occur during sport participation (Sosin et al., 1991) with the greatest prevalence in high school football (Gerberich, Priest, Boen, Staub, & Maxwell, 1983). True occurrence rates are likely higher than estimated, as one recent investigation found over 50% of high school athletes did not report their concussion to sports medicine personnel (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Although sport concussions represent only a portion of all head injuries, studying these individuals offers the advantage of acquiring preinjury data on a sample with a known injury rate. Establishing preseason neurocognitive functioning provides the clinician a point of comparison in the event that a player is concussed during sport participation.

Concussion results from a direct or indirect blow to the head that causes neuropathologic changes to brain tissue (Aubry et al., 2002). The functional alterations in brain rather than structural changes to brain tissue may manifest in a myriad of patterns (Giza & Hovda, 2001). No definitive diagnostic tool exists for the clinician to use during the injury assessment, making the evaluation largely subjective. In addition, multiple variables may influence injury outcomes. Factors relating to the previous number of injuries (Guskiewicz et al., 2003), impact location (Pellman, Viano, Tucker, Casson, 2003), and impact magnitude (Pellman, 2003) may all play a role in the injury's manifestations. As such, arrays of tests have been compiled that evaluate multiple aspects of cognitive functioning. The battery is widely accepted to include assessments of self-report symptoms, postural control, and neurocognitive functioning (Guskiewicz et al., 2004; McCrory et al., 2005).

The neurocognitive assessment is suggested to serve as the cornerstone of the concussion assessment (Aubry et al., 2002), but the pervasive nature of the injury warrants the assessment of multiple aspects of cognitive functioning. Domains such as information processing, planning, memory, and cognitive flexibility have been recommended (Aubry et al., 2002). An evaluation of task performance (e.g., response time [RT]) has also been suggested as a stable measure of cognitive functioning that is sensitive to concussion's effects (Collie, Maruff, McStephen, & Darby, 2003). This measure is of particular interest with regards to the recent influx and use of computer-based assessments into clinical practice (Notebaert & Guskiewicz, 2005) that offer the advantage of precision RT measures. Thus, the inclusion of cognitive tasks that tap specific cognitive processes may provide evidence for the impact of concussion on cognitive functioning.

Much of the current literature has focused on mean changes in cognitive performance and has indicated delays in RT immediately following injury (Collie, Makdissi, Maruff, Bennell, & McCrory, 2006; Iverson, Brooks, Collins, & Lovell, 2006) that remain after physical symptoms have been alleviated (Warden et al., 2001). As such, mean RT is believed to provide a meaningful index of neurological function in concussed individuals. The justification for prolonged RT has not been fully elucidated, but it has been suggested that concussion may directly affect regions of the brain responsible for maintaining attention, thus slowing the ability to process and respond to external information slowing RT (Halterman et al., 2006).

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Recently, intraindividual variability in cognitive processing speed has been suggested as a marker of overall neurological health (MacDonald, Nyberg, & Backman, 2006). This proposition is supported by empirical evidence showing that the level of intraindividual variability distinguishes groups on the basis of age (Hultsch & MacDonald, 2004), disease status (Castellanos & Tannock, 2002), and cognitive function (MacDonald, Hultsch, & Dixon, 2003; Stuss, Pogue, Buckle, & Bondar, 1994). It is important to note that group identification based on variability exceeds the predictive ability of RT mean performance. Intraindividual variability is therefore believed to confer unique information about cognitive functioning (Hultsch & MacDonald, 2004; MacDonald et al., 2006). Although the underlying neurophysiological factors contributing to intraindividual-variability increases are not clear (MacDonald et al., 2006), there is evidence that elevated RT variability is an indicator of prefrontal and frontal lobe dysfunction (Hausdorff et al., 2006; Stuss, Murphy, Binns, & Alexander, 2003). The involvement of these regions in cognitive processes necessary for task performance warrants the examination of RT variability as valuable information for understanding changes in cognition following concussion.

Despite its status as a marker of neurological health, there is limited research focusing on the variability of cognitive functioning in concussed individuals. The few studies that have been conducted yield contradictory results. For instance, Makdissi and colleagues (2001) reported that six concussed participants had elevated variability during completion of a simple RT task. In contrast, Halterman and colleagues (2006) observed that there was no increase in relative RT variability (i.e., coefficient of variation) in 20 concussed participants on various components of a visuospatial attention task. Although differing methodologies may account for the discrepant results, the effect concussion has on cognitive variability remains unclear.

Despite conflicting evidence in the literature, it is hypothesized that concussion will result in increased intraindividual variability. This prediction is based, in part, on the well-established deficits in cognitive function witnessed in concussed individuals. Sufficient evidence exists to suggest that variability in cognitive processing is elevated in individuals with decrements in cognitive function. Lastly, a recent report found that older adults with postural control impairments also demonstrate increased RT variability (Hausdorff et al., 2006). Because concussion is known to impact postural control (Guskiewicz, Riemann, Perrin, & Nashner, 1997; Guskiewicz, Ross, & Marshall, 2001; McCrea et al., 2003), it follows that individuals suffering a concussion will likewise demonstrate an increase in cognitive variability.

Consequently, the purpose of the current investigation was to retrospectively evaluate RT, RT variability (standard deviation), and accuracy in concussed participants and normal healthy adults on assorted components of a cognitive test commonly used for concussion assessment. It was predicted that concussed participants will have prolonged RT, increased intraindividual variability, and less accurate responses.

Method

Participants and Procedure

As part of an ongoing investigation of mild traumatic brain injuries in sport, all varsity athletes at high risk for concussion were administered a baseline neurocognitive assessment prior to the competitive season. The Baseline Headminder Concussion Resolution Index (CRI) test (Erlanger, Feldman, Kutner, & McCrea, 2001) was administered simultaneously to small groups of athletes in a computer laboratory with an administrator overseeing the testing. In the event an athlete sustained a physician-diagnosed concussion, a follow-up assessment was administered within 48 hours of injury. All participants read and signed an institutional review board informed consent prior to testing.

Twenty-two athletes with valid baseline assessments were evaluated within 48 hours of concussion between 2001 and 2003. The median time between the baseline evaluation and the postconcussion assessment was 173.1 ($\pm$ 171.3; range = 16.0–514.0) days. The group consisted of 2 female and 20 male athletes with a mean age of 19.8 ($\pm$ 2.2) years. Thirteen athletes reported a previous history of concussive injuries ranging from one to three incidences. In 2005, 123 college-age control participants were evaluated twice on the CRI. The mean interval between the two tests was 44.8 ($\pm$ 1.8) days. The group consisted of 81 female participants and 43 male participants with a mean age of 21.9 ($\pm$ 2.7) years. Twenty-two age- and gender-matched participants were chosen from the control cohort to serve as nonconcussed control participants. Because it is well known that attention deficit disorder can interact with cognitive functioning (Collins et al., 1999), participants reporting attention deficit disorder or other learning disabilities were excluded from the analyses.

The CRI is a 20-minute, Internet-based assessment of neurocognitive functioning that was designed specifically for concussion evaluation. The test has been described in detail elsewhere (Erlanger et al., 2003) but consists of six subtests: RT, cued RT (CuRT), visual recognition 1 (VR1), visual recognition 2 (VR2), animal decoding, and symbol scanning (SS). The RT task presented the participant with a series of shapes and required the space bar to be pressed as quickly as possible when a white circle appeared. Mean and standard deviation of RT were calculated from 25 trials. CuRT consisted of 70 trials that required the participant to depress the space bar as quickly as possible when a black square preceded a white circle during the presentation of a series of shapes. During the VR1 task, a series of pictures was presented to the participant. When a picture was repeated, the participant was required to press the space bar as quickly as possible. The VR2 presented a second series of pictures to the participant. If a picture from the VR1 task was shown, the participant was required to press the space bar. Both the VR1 and VR2 consisted of 60 trials each, and an interim task separated the subtests. In the SS, two shapes were presented in the left visual hemifield, and eight shapes were presented in the right visual hemifield. The participant's task was to scan the eight shapes and determine if one (indicated with the number one key) or two (indicated with the number two key) shapes were also presented on the left. A total of 30 trials were presented in the SS. The standard deviation for animal decoding was not recorded and consequently was not included in the current analysis.

Data Analysis

Multiple mixed model (Group $\times$ Day) repeated measures analyses of variance (ANOVAs) were implemented to evaluate differences between concussed and healthy participants' RT, response accuracy, and RT variability performance on the baseline and follow-up assessments. It is possible that changes in RT variability are not unique markers of cognitive dysfunction following concussion but rather proportional to increases in mean RT following concussion. Thus, analyses of covariance (ANCOVA) were conducted on intraindividual standard deviation RT, with mean RT performance in the follow-up assessment used as a covariate. All analyses were completed by using SPSS version 13.0 (SPSS Inc., Chicago, IL), and significance was noted when $p < .05$.

Results

Mean RT

To examine the effect of concussion on mean RT in the five cognitive tasks, a two-way mixed model ANOVA with day (baseline/follow-up) as the repeated measures within-subject factor and group (healthy/concussed) as the between-subjects factor was conducted on mean RT for each task. Figure 1 clearly shows an increase in RT across all five tasks in the participants following injury when compared with RT from their baseline assessments (see Table 1). It is important to note that a significant increase in the healthy participants' RT was not observed from baseline to follow-up, indicating general decrements in cognitive function only for the concussed group. In fact, the healthy group demonstrated improved performance (as measured via shorter RT) on the SS task (3.03 s vs. 2.77 s), likely reflecting a practice effect, whereas the concussed group exhibited a decrease in performance (3.31 vs. 3.83 s; $p < .05$), likely related to injury.

Accuracy

The increase in concussed participants' RT may have resulted from a shift in strategy from focusing on speed of response to focusing on accuracy. To examine this possibility a mixed model ANOVA with day (baseline/follow-up) as the repeated measures within-subject factor and group (healthy/concussed) as the between-subjects factor was conducted on accuracy (i.e., number correct) for each cognitive task. Overall, it was found that concussed participants had lower accuracy only in the CuRT task following injury when compared with that from their baseline performance and that of the healthy group at the same time point (see Figure 2; Table 2). There was no significant change in accuracy across measurement occasions in the healthy group. Accordingly, these data indicate that increases in mean RT for the concussed group were not related to a shift in cognitive strategy.

Standard Deviation of RT

Concussed participants demonstrated more RT variability (i.e., greater *SD*) following injury, whereas the healthy participants did not demonstrate changes in variability across occasions (Figure 3; Table 3). It is important to note that there was no effect of day on RT *SD* in the healthy group across the five tasks. In contrast, there

Table 1
ANOVA Table for Mean Response Time

Task	Factor	*df*	*F*	η^2
SRT	Day	(1, 42)	12.9*	.24
	Group	(1, 42)	6.87*	.14
	Day × Group	(1, 42)	13.5*	.24
CuRT	Day	(1, 42)	15.6*	.27
	Group	(1, 42)	15.7*	.27
	Day × Group	(1, 42)	13.5*	.24
VR1	Day	(1, 42)	23.4*	.36
	Group	(1, 42)	19.9*	.32
	Day × Group	(1, 42)	11.9	.22
VR2	Day	(1, 42)	14.1*	.26
	Group	(1, 42)	16.8*	.29
	Day × Group	(1, 42)	8.7*	.17
SS	Day	(1, 42)	1.0	.02
	Group	(1, 42)	15.6*	.27
	Day × Group	(1, 42)	5.40	.11

Note. ANOVA = analysis of variance; SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.
* $p < .05$

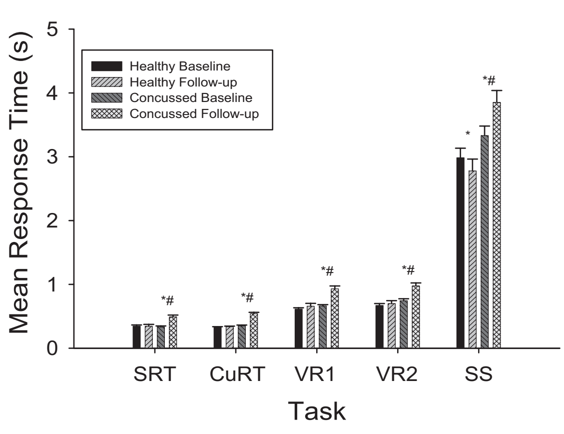

Figure 1. Mean response time (*SE* indicated with bars) as a function of task, day, and group. * within group, between day $p < .05$; # within day, between group $p < .05$. SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.

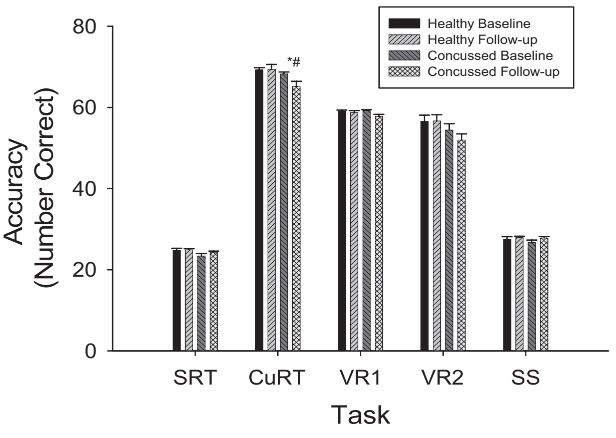

Figure 2. Accuracy (number correct; *SE* indicated with bars) as a function of task, day, and group. * within group, between day $p < .05$; # within day, between group $p < .05$. SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.

Table 2
ANOVA Table for Accuracy

Task	Factor	*df*	*F*	η^2
SRT	Day	(1, 42)	2.1	.05
	Group	(1, 42)	3.5	.08
	Day × Group	(1, 42)	1.0	.02
CuRT	Day	(1, 42)	4.1*	.09
	Group	(1, 42)	5.9*	.12
	Day × Group	(1, 42)	4.3*	.09
VR1	Day	(1, 42)	5.3*	.11
	Group	(1, 42)	0.77	.02
	Day × Group	(1, 42)	1.8	.04
VR2	Day	(1, 42)	1.23	.03
	Group	(1, 42)	3.3	.07
	Day × Group	(1, 42)	1.5	.03
SS	Day	(1, 42)	2.9	.07
	Group	(1, 42)	0.58	.01
	Day × Group	(1, 42)	0.77	.02

Note. ANOVA = analysis of variance; SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.
* $p < .05$

Table 3
ANOVA Table for Standard Deviation of Response Time

Task	Factor	*df*	*F*	η^2
SRT	Day	(1, 42)	0.06	.00
	Group	(1, 42)	5.5*	.12
	Day × Group	(1, 42)	1.3	.03
CuRT	Day	(1, 42)	6.6*	.14
	Group	(1, 42)	11.8*	.22
	Day × Group	(1, 42)	2.2	.05
VR1	Day	(1, 42)	8.4*	.17
	Group	(1, 42)	9.6*	.18
	Day × Group	(1, 42)	3.3	.07
VR2	Day	(1, 42)	8.6*	.17
	Group	(1, 42)	10.9*	.21
	Day × Group	(1, 42)	0.8	.02
SS	Day	(1, 42)	0.49	.00
	Group	(1, 42)	13.6*	.24
	Day × Group	(1, 42)	4.8*	.10

Note. ANOVA = analysis of variance; SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.
* $p < .05$.

was a significant effect of day in the concussed group with RT *SD* increasing following injury in all tasks except the SS task.

It has been suggested that increases in RT variability in concussed individuals reflects the increase in mean RT (cf. Halterman et al., 2006). That is, RT *SD* parallels mean RT and offers no unique information concerning cognitive function. As such, this concept was explored with multiple ANCOVAs on RT variability in the five tasks, with day serving as a repeated measures within-subject factor, group as between-subjects factor, and follow-up mean RT as the covariate. Results from this analysis (see Figure 4; Table 4) indicate that the effect of a concussion on RT *SD* was eliminated when controlling for mean postconcussion RT. Specifically, there were no significant differences ($p > .05$) in RT *SD* between healthy and concussed participants across all tasks. These results indicate that RT *SD* does not provide unique information concerning cognitive function above and beyond that contained in mean RT.

Discussion

Intraindividual variability in RT has recently been reported as a unique marker of neurological function (MacDonald et al., 2006). For instance, elevated intraindividual variability has been found to predict decreases in cognitive function in the elderly (MacDonald, et al., 2003) and be elevated in individuals with attention deficit disorders (Castellanos & Tannock, 2002). Moreover, the ability to distinguish between groups by an individual's variability exceeds that of mean RT alone, and in some instances variability may confer more information than will any other performance marker

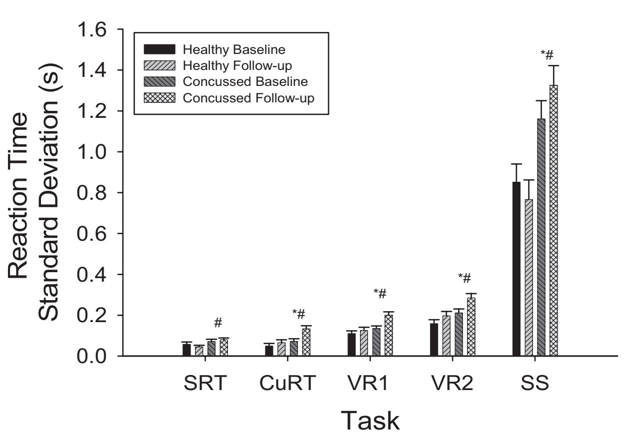

Figure 3. Standard deviation of response time (*SE* indicated with bars) as a function of task, day, and group. * within group, between day $p < .05$; # within day, between group $p < .05$. SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.

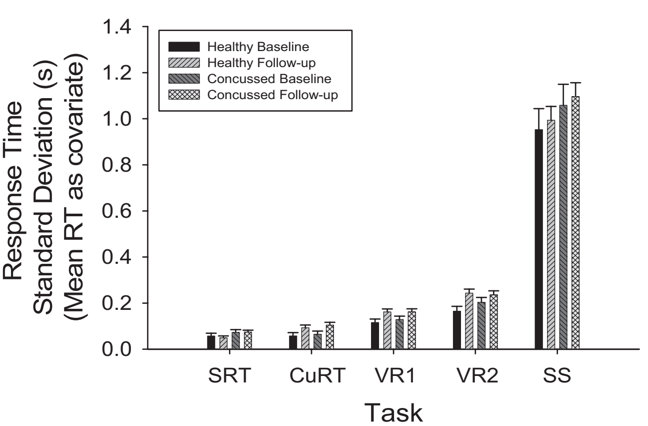

Figure 4. Standard deviation of response time (*SE* indicated with bars) with mean response time at follow-up as covariate as a function of task, day, and group. RT = response time; SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.

Table 4
ANCOVA Table for Standard Deviation of Response Time With Mean Response Time Controlled For

Task	Factor	*df*	*F*	η^2
SRT	Day	(1, 41)	1.57	.04
	Group	(1, 41)	0.30	.07
	Day × Group	(1, 41)	0.67	.00
CuRT	Day	(1, 41)	1.2*	.03
	Group	(1, 41)	0.61	.02
	Day × Group	(1, 41)	0.02	.00
VR1	Day	(1, 41)	8.1*	.16
	Group	(1, 41)	0.20	.00
	Day × Group	(1, 41)	0.16	.00
VR2	Day	(1, 41)	7.1*	.15
	Group	(1, 41)	0.64	.02
	Day × Group	(1, 41)	1.3	.03
SS	Day	(1, 41)	14.3*	.26
	Group	(1, 41)	1.0	.02
	Day × Group	(1, 41)	0.0	.00

Note. ANCOVA = analysis of covariance; SRT = simple response time; CuRT = cued response time; VR = visual recognition; SS = symbol scanning.
* $p < .05$.

(Collins et al., 1999). Consequently, the purpose of this investigation was to examine the influence of concussion on intraindividual variability (i.e., *SD* of RT) in cognitive functioning.

Congruent with previous reports, concussed participants were found to respond more slowly across tasks tapping a variety of cognitive functions following trauma (Iverson, Brooks, Collins, & Lovell, 2006; McClincy, Lovell, Pardini, Collins, & Spore, 2006). Concussed participants also demonstrated decreased accuracy of responses compared with that of their healthy counterparts, albeit only in the CuRT task. This highlights the validity of RT and accuracy of responses as a marker of neurocognitive dysfunction in concussed participants. Speculation surrounds the cause of neurological dysfunction following concussion (Chen, Kareken, Fastenau, Trexler, & Hutchins, 2003; Hofman, Verhay, Wilmink, Rozendaal, & Jolles, 2002), but decrements in RT and response accuracy may be related to transient functional changes to neurological tissue (Giza & Hovda, 2001).

When controlling for follow-up RT, no significant differences in RT variability between groups were observed for any task. This lack of an effect is congruent with a previous report indicating no difference in the RT coefficient of variation (standard deviation divided by the mean) between concussed and healthy participants during performance of a visuospatial attention task (Halterman et al., 2006). It is important to note that results indicated concussed individuals did not exhibit greater RT *SD*, but rather their increase in variability was proportional to their increase in mean RT (i.e., slowing). Thus, by accounting for changes in postconcussion mean RT, the intraindividual RT variability does not provide unique information concerning neurological function. Additionally, this proportional increase in RT variability explains the discrepancy in the literature concerning RT variability, discussed previously. Simply stated, differences reported between investigations appear to be related to whether changes in mean RT following concussion were taken into account. Investigations not accounting for mean RT changes reported elevated RT *SD* (Makdissi et al., 2001), whereas those controlling for mean RT reported no difference in RT *SD* in concussed individuals (Halterman et al., 2006).

The proportional increase in RT variability as a function of mean RT contrasts with previous research examining changes in intraindividual cognitive variability in various populations. A major distinction between this investigation and those reporting variability as a predictor of neurocognitive function is the population under investigation. Previous research examined populations with structural changes to the brain due to factors such as advanced age, pathology, and severe traumatic brain injury (see Hultsch & MacDonald, 2004, for review). This contrasts sharply with the current study population, who suffered from transient nonstructural changes stemming from concussion. Although these populations share similar behavioral characteristics, the underlying factors driving these behavioral similarities are diverse. Additionally, the proportional increase in the mean and variability of performance is congruent with Crawford and Garthwaite (2006), who proposed that it is difficult to imagine how a lesion could increase variability without influencing mean performance. Moreover, they suggested (Crawford & Garthwaite, 2006) that if mean performance was not reduced, then scores below those recorded prior to the injury performance would have to be exactly matched by scores that exceeded the premorbid level. Moreover, this discrepancy suggests that the transient neurological dysfunction induced by concussive impacts is responsible for increases in mean RT but not for elevated intraindividual cognitive variability.

Given the lack of neuroimaging tools to measure specific trauma-related changes in brain function associated with cognitive task performance, discussion regarding the mechanisms associated with the acute trauma-related decrements in task performance remains speculative. However, given most of the tasks used to examine the effect of a concussion on cognition have involved some aspect of the attentional networks, it would follow that this network is responsible, in part, for the observed changes in cognitive performance. Norman and Shallice (1986) developed a top-down model of attentional control, which proposed that routine mental procedures were carried out by a contention scheduling process that allowed for multiple processes to occur in a simultaneous and efficient manner. However, during more difficult or nonautomatic processes, the supervisory attentional system was required to regulate contention scheduling processes through the inhibition and excitation of competing action schemas (Norman & Shallice, 1986).

More recent work by Stuss and his colleagues (2005) used three RT tasks requiring multiple aspects of attention in a sample of patients with lesions to their frontal lobes and determined that cognitive performance on these tasks was decreased relative to healthy control participants. Specifically, Stuss et al. (2005) measured simple RT, choice RT, and prepare RT (i.e., processes involved in getting ready for a task that follows closely after a warning cue) to examine the effect of localized frontal lobe lesions on task performance. These tasks were chosen because they reflect the most basic processes related to the anterior attentional network (Stuss et al., 2005). Accordingly, given that the battery of tests performed herein required multiple aspects of the anterior attentional network examined by Stuss et al. (2005) and that performance on these tasks suffered following acute trauma, it would follow that the anterior attentional network trauma is directly related to the cognitive decrements observed following concussion. Clearly, additional research efforts using neuroimaging techniques and cognitive tasks that engage the anterior attentional network are needed to better elucidate the relationship between acute trauma and cognition.

The time interval between the initial and follow-up assessments differed between the concussed (173 days) and the nonconcussed groups (45 days). Ideally, both groups would be tested with the same interval between sessions, but the unpredictable nature of concussion incidence makes matching test intervals difficult. It is possible that group differences result from the different follow-up durations, but we find this unlikely as the test–retest reliability of the CRI has been shown to be acceptable for clinical application (Erlanger et al., 2001). To further explore the potential interaction between the duration of follow-up assessment and test performance, we explored the data set by controlling for the time interval between assessments through additional ANCOVA analyses. No significant differences were observed in the effect of concussion on mean and *SD* of RT performance when follow-up time was controlled.

However, caution should be taken when interpreting the ANCOVA results. ANCOVAs do not control for the difference in systematic and unsystematic within-subject variation inherent in the individual *SD*. As such, it is possible that observed group differences result from differences in practice effects or fatigue as opposed to the grouping variable (i.e., concussion). There are other techniques available such as hierarchical linear modeling that are capable of partialing out systematic and unsystematic variance. Reports that document independence between mean performance and variability of performance in chronic conditions have used these distinct techniques (cf. Hultsch, MacDonald, & Dixon, 2002). Thus, the possibility remains that the lack of congruence between the current observations and previous reports is not a result of population differences but rather differences in statistical analysis. Further work examining this discrepancy is warranted.

The current investigation demonstrated that the transient neurological dysfunction induced by exogenous impacts resulting in concussion are responsible for increases in mean RT but not for elevated intraindividual cognitive variability (i.e., RT *SD*). This observation supports the proposition that the mean RT and RT variability are independent neurocognitive mechanisms (MacDonald et al., 2006). Although evidence suggests that alterations in the attentional network are contributing to increases in mean RT following injury (Halterman et al., 2006), further investigations using more sophisticated evaluative measures are needed to identify these networks.

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