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Effect of Sport Related Concussion on Clinically Measured Simple Reaction Time

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Abstract

Background—Reaction time (RT) is a valuable component of the sport concussion assessment battery. RT is typically measured using computers running specialized software, which limits its applicability in some athletic settings and populations. To address this, we developed a simple clinical test of RT (RT_{clin}) that involves grasping a falling measuring stick.

Purpose—To determine the effect of concussion on RT_{clin} and its sensitivity and specificity for concussion.

Materials and methods—Concussed athletes (n=28) and non-concussed control teammates (n=28) completed RT_{clin} assessments at baseline and within 48 hours of injury. Repeated measures ANOVA compared mean baseline and follow-up RT_{clin} values between groups. Sensitivity and specificity were calculated over a range of reliable change confidence levels.

Results—RT_{clin} differed significantly between groups ($p < .001$): there was significant prolongation from baseline to post-injury in the concussed group ($p = .003$), with a trend toward improvement in the control group ($p = .058$). Sensitivity and specificity were maximized when a critical change value of 0 ms was applied (i.e., any increase in RT_{clin} from baseline was interpreted as abnormal), which corresponded to a sensitivity of 75%, specificity of 68%, and a 65% reliable change confidence level.

Conclusions—RT_{clin} appears sensitive to the effects of concussion and distinguished concussed and non-concussed athletes with similar sensitivity and specificity to other commonly used concussion assessment tools. Given its simplicity, low cost, and minimal time requirement, RT_{clin} should be considered a viable component of the sports medicine provider's multifaceted concussion assessment battery.

INTRODUCTION

Sport related concussion (SRC) is common¹ and there is increasing concern regarding possible long term effects.^{2–4} While concussed athletes typically recover symptomatically within one to two weeks,^{5, 6} an athlete whose concussion is unrecognized or who returns to play prematurely is put at risk for more significant injury.⁷ Thus, prompt recognition of SRC and accurate determination of its resolution are important. However, SRC remains a

diagnostic challenge. Presentations are variable and often subtle, and athletes may minimize their symptoms.⁸ While a growing number of assessment tools have been developed, the diagnosis of SRC remains a clinical one.

Current consensus opinion advocates a multifaceted approach to concussion assessment.^{9–11} Clinical tools are available to evaluate many aspects of concussion including symptoms,¹² neurocognitive function,¹³ and balance.¹⁴ Computer-based neurocognitive assessment tools capable of measuring reaction time, attention, working memory, and problem solving are also available.^{15–17} Such tools can be valuable, but their computer-dependence, time requirement, and cost limit their applicability in some situations (e.g., acute concussion diagnosis) and environments (e.g., communities with limited financial resources).

A prolonged reaction time (RT) is common following SRC, and is one of the most sensitive indices of neurocognitive change following injury.^{18, 19} In addition RT has been shown to have prognostic value²⁰ and commonly parallels other concussion symptoms.^{21–24} Moreover, a prolonged RT can persist beyond symptom resolution, suggesting incremental value over solely tracking post-concussive symptoms.^{5, 25, 26}

Despite these advantages, computer-independent methods for assessing RT are not available. To address this, we developed a simple, inexpensive method for clinically assessing RT, referred to as clinical RT (RT_{clin}). RT_{clin} is a visuomotor test in which the subject arrests a falling object by hand closure after it is released by an examiner. Pilot work demonstrated the short and long term reliability of RT_{clin},^{27, 28} and its validity with relation to a computerized measure of RT in athletes.²⁹ Furthermore, the task appears to be intrinsically motivating,³⁰ an important characteristic for situations in which an athlete's after-injury performance is compared to pre-season baseline.³¹ Unlike other tests of RT, RT_{clin} has demonstrated functional relevance by showing a strong correlation with an athlete's ability to protect their head in a laboratory simulated athletic environment.³² Recently, we reported a 13.5% prolongation of RT_{clin} in 9 collegiate athletes tested within 72 hours of SRC as compared to baseline.³³ Although the results are suggestive, a larger, controlled study is needed to further elucidate the clinical usefulness of RT_{clin}. Therefore, the purpose of this study is to determine the effect of concussion on RT_{clin} in a larger sample of high school and collegiate athletes through a controlled study design. We hypothesized that RT_{clin} would be prolonged in concussed athletes as compared to baseline and non-concussed control athletes.

METHODS

Subjects

Male and female athletes participating in multiple sports at two universities and one high school were recruited during pre-participation physical examinations over two consecutive seasons. Potential subjects were excluded if they were recovering from a concussion or had an upper limb injury preventing the completion of the RT_{clin} task. Adult athletes provided institutional review board (IRB) approved informed written consent and minor athletes provided IRB-approved assent with accompanying parental consent.

Testing Schedule

RT_{clin} was measured in all athletes at baseline during pre-participation examinations. RT_{clin} was determined again within 48 hours of injury in athletes who sustained a physician-diagnosed concussion. For each injured athlete, a control athlete who was a member of the same team and was present in the training room for a reason other than concussion was also retested.

Measuring RT_{clin}

The protocol for RT_{clin} testing has been previously described^{28, 29} and is illustrated in Figure 1. The RT_{clin} apparatus is an 80 cm rigid measuring stick coated in friction tape with a weighted rubber disk affixed to one end. Athletes sat with their dominant forearm resting on a table with their hand positioned over its edge. The hand was open surrounding, without touching, the weighted disk portion of the RT_{clin} apparatus. The examiner suspended the device vertically such that the top face of the disk was aligned in the plane defined by the top of the athlete's open hand. After pre-determined randomly assigned delays ranging from 2 to 5 seconds, the examiner released the apparatus and the athlete caught it as quickly as possible by hand closure. For each trial, a RT_{clin} value (in ms) was calculated from the distance (in cm) that the device fell using the formula for a body falling under the influence of gravity ($d = \frac{1}{2}gt^2$). After 2 practice trials, each athlete completed 8 data acquisition trials and a mean RT_{clin} value was calculated for the test session. The mean RT_{clin} value was used for analysis. RT_{clin} change scores were determined by the difference between baseline and follow-up values (follow-up RT_{clin} – baseline RT_{clin}) so that a positive RT_{clin} change score represents a decline from baseline, while a negative score represents improvement.

Data Analysis

A 2-way repeated measures ANOVA, with paired t-tests used post-hoc, was used to compare preseason and after-injury RT_{clin} values in concussed versus control athletes. The effect sizes of the RT_{clin} changes observed were described using Cohen's d. Reliable change calculations were performed using standard deviations of difference scores (SD_{diff}) from the control group.³⁴ An adjusted reliable change equation, controlling for practice effects,³⁵ was used:

$$RC = [(x_2 - x_1) - (\mu_2 - \mu_1)] / SD_{diff}$$

where $x_2 - x_1$ is the individual performance difference between follow-up (x_2) and baseline (x_1) RT_{clin} in a concussed athlete; $\mu_2 - \mu_1$ is the mean group difference between follow-up (μ_2) and baseline (μ_1) RT_{clin} in the control group; and SD_{diff} is the standard deviation of the change scores for the control group. An adjusted reliable change index has been demonstrated to perform comparably to more complex regression-based formulas^{36–38} and has been advocated over regression-based methods.³⁶

Reliable change values can be interpreted by comparing them to the z-distribution critical value associated with a desired one-tailed probability of error. One-tailed critical values were used because the outcome of interest was a decline in performance from baseline, rather than any difference, which could represent either decline or improvement.^{39, 40} For example, a critical value of 1.65 is used when a 5% type I error rate is deemed acceptable. Therefore a reliable change score greater than 1.65 can be interpreted as an indication that an athlete has experienced a significant decline in their RT_{clin} performance, with a 5% probability of Type I error.

Conversely, once the mean RT_{clin} change score and its associated standard deviation are calculated in the control group, a cut-off value can be generated indicating the RT_{clin} change score that represents significant change at a given level of confidence. We calculated reliable change cut off values over a range of confidence levels and determine the combined sensitivity and specificity associated with each value.⁴¹ In addition, a receiver operating characteristic curve (ROC curve) was generated to compare the sensitivity and specificity associated with cut-off value over the range of RT_{clin} change scores observed. Sensitivity

and specificity values were summed at each cut off value, with the highest summed score interpreted as having the greatest combined sensitivity and specificity.^{41, 42}

RESULTS

Twenty-six athletes sustained 28 concussions (with 2 athletes sustaining repeat concussions) over the 2 year study. The majority of concussions occurred in male collegiate football players ($n=20$, 71.4%). The remaining injuries were sustained by athletes participating in male high school football ($n = 2$, 7.1%), female collegiate soccer ($n = 2$, 7.1%), male collegiate ice hockey ($n = 1$, 3.6%), and male high school ice hockey ($n = 1$, 3.6%). Of note, two injuries which occurred during Year 2 involved athletes who did not have baseline RT_{clin} results available from that year. Therefore, Year 1 baseline RT_{clin} results were used for these subjects and for their matched controls. The time from baseline to follow-up RT_{clin} testing did not differ between the concussed and control groups (mean $\pm$ SD = 60.5 ± 40.5 and 73.8 ± 51.0 days, respectively; $p = 0.631$).

Concussed and control athletes demonstrated nearly identical mean ($\pm$ SD) baseline RT_{clin} values (203 ± 22 ms vs. 202 ± 16 ms, respectively; $p = .839$). After-injury RT_{clin} values were significantly greater (longer) as compared to baseline (220 ± 29 ms; $p = .003$; effect size, $d = 0.616$), while there was a trend toward shorter RT_{clin} values in the 28 controls (193 ± 17 ms, $p = .058$; effect size, $d = -0.373$). The group by test interaction was highly significant ($p < .001$). The contrast between baseline and follow-up RT_{clin} in the two groups is illustrated in Figure 2.

Reliable change cut off values for RT_{clin} and the associated sensitivity and specificity at each confidence level are presented in Table 1. The cut off values represent the RT_{clin} change values necessary to conclude that an athlete has experienced a significant prolongation in RT_{clin} at a given level of confidence. An ROC curve comparing the sensitivity and specificity of RT_{clin} at every possible cut off value over the observed range of RT_{clin} change values was also generated (Figure 3). Resulting analysis demonstrated that cut off values from 0ms to -2ms (i.e., 2 ms of improvement at follow-up) maximized sensitivity and specificity of RT_{clin} with a combined value of 1.43. This corresponds to a critical value of 0.375 and an associated one-sided confidence level of 65%.

DISCUSSION

In this study we observed a significant decline in RT_{clin} performance following SRC in a group of 28 concussed athletes (8.4% slower RT). These results are similar to those previously reported.³³ The effect size reported here is generally considered to be moderate in size.⁴³ In contrast, follow-up RT_{clin} performance showed a trend toward improvement in the control athletes. Group analyses showed that the contrast between post-injury performance declines observed in the injured athletes versus the improvement in controls was highly significant.

Reliable change analyses allow group data to be applied to individuals. We found that to be 95% confident an athlete's RT_{clin} performance has declined, RT_{clin} must be at least 31 ms slower during follow up testing. Using this cut-off value correctly identifies 11 of the 28 concussed athletes studied (39% sensitivity), but it incorrectly identifies just 2 of the 28 control athletes as having performed worse (93% specificity). Conversely, if we choose to be 60% confident that an athlete's follow-up RT_{clin} performance is worse the cut-off value is 3ms improvement from baseline, due to the non-concussed athletes having faster RT_{clin} at follow-up. These control athlete data suggest a small learning effect, consistent with prior observations.²⁷ Using this 3 ms improvement cut-off value correctly identifies 22 of the 28

concussed athletes (79% sensitivity), while incorrectly identifying 11 of the 28 control athletes (61% specificity).

Screening tests should have high sensitivity so as to identify the majority of affected individuals. Given the inherent trade-off between sensitivity and specificity, an increased sensitivity invariably results in an increased false positive rate. However, given the current “when in doubt sit them out” approach with regard to concussion, this trade off seems appropriate. This is especially true in younger athletes, where the consequences of a missed injury are greatest.⁷ Moreover, maximizing test sensitivity at the expense of specificity has been advocated by other groups with regard to concussion assessment tools.^{42, 44–47} In our study, a change score of 0 ms (i.e., interpreting any follow up RT_{clin} value that is slower than baseline as abnormal) was found to maximize the combined sensitivity (75%) and specificity (68%) of the test and correlated with a reliable change confidence level of 65%. Therefore we propose an RT_{clin} cut-off value of 0ms be used when screening an athlete with suspected concussion.

The test characteristics for RT_{clin} reported here are similar to other recognized concussion assessment tools. For example, McCrea et al. reported on the sensitivity and specificity of four commonly used assessment tools.⁴⁷ Test sensitivities were highest when testing occurred within 3 hours of injury, with the Graded Symptom Checklist (GCS) being the most sensitive (89% sensitive, 100% specific), followed by the Standardized Assessment of Concussion (SAC; 80% sensitive, 91% specific), and the Balance Error Scoring System (BESS; 34% sensitive, 91% specific). The neuropsychological test battery administered 2 days following injury had a sensitivity and specificity of 23% and 93%. At the same 2 day post injury interval the sensitivity/specificity of the GSC, SAC, and BESS dropped substantially to 27%/100%, 22%/89%, and 24%/91%, respectively. Overall a marked reduction in sensitivity was observed for each test over the first week following injury. The authors also noted that combinations of tests had greater sensitivity than individual tests. Broglio et al. later reported on the sensitivity of 5 different concussion assessment tools.⁴⁸ The most sensitive measure was the Immediate Post-concussion Assessment Cognitive Test (ImPACT) (79.2%), with its most sensitive component being the symptom inventory (62.5%). The combined sensitivity of the remainder of the ImPACT battery was 62.5%, with the memory and reaction time composite scores being the most sensitive individual tests (41.7% each). The overall sensitivity of the HeadMinder Concussion Resolution Index was 78.6%, with individual test component sensitivities of 71.4% for simple and complex reaction time and 50% for processing speed. A 9 item concussion symptom scale was the next most sensitive tool (68%). As was the case in McCrea’s study, test batteries demonstrated greater sensitivity than any single component used in isolation. The specificities of these tests were not reported. Other relevant studies in this regard are summarized in Table 2.

In aggregate, the sensitivity and specificity of concussion assessment tools are greater when the test is conducted immediately following injury, with a gradual decline in sensitivity over time. It also appears that test batteries with multiple components are more sensitive than individual measures. With these considerations in mind, it is remarkable that RT_{clin}, a single 5 minute test that was performed up to 48 hours after injury with equipment costing less than 5 US dollars, has comparable test characteristics to other concussion assessment tools currently in use, including lengthier computerized neuropsychological test batteries composed of multiple individual tests (e.g., ImPACT, CRI), traditional paper and pencil neuropsychological test batteries (composed of the HVLT, TMT, SDMT, DS, COWAT and Stroop), and costly balance assessment tools (e.g., SOT). Further research should evaluate the test characteristics of a concussion assessment battery composed entirely of clinical assessment tools such as a symptom checklist, the SAC, RT_{clin}, and the BESS. Such a

battery is likely to have improved sensitivity over its individual component measures, and could easily be used by sports medicine providers in nearly any location at minimal expense.

The control athletes represent one of the study's strengths. These athletes were re-tested at similar time intervals as their concussed teammates and were typically receiving treatment for non-concussive injuries at the time of follow up assessment. This is important and suggests that the concussed athletes' altered RT_{clin} performance is more likely related to their concussions than to other in-season factors affecting the team that were not measured or directly controlled for in our study design. In addition, the results are more compelling given prior work finding RT_{clin} to be valid, intrinsically motivating, and functionally relevant.^{27–30, 32} The study also has limitations that merit discussion. The majority of concussed athletes were male collegiate football players, and so the generalizability of this study's findings to other populations is uncertain. Also, the athletes underwent after-injury testing at a single time point within 48 hours of concussion, and so no information regarding a post-injury "recovery curve" is available. Furthermore, in some cases the follow up tests on control athletes were not conducted on the exact same day as the after-injury tests in their concussed teammates. We do not suspect that these generally small differences in time until follow up testing have introduced significant bias, however their effect is not known. Finally, examiners were not blinded to athletes' concussion status during follow up testing and so the introduction of measurement bias is possible. This is less likely given the nature of the task, which occurs on a millisecond scale, and given that examiners were not aware of the athlete's baseline performance.

In conclusion, the results suggest that RT_{clin} performance is impaired following concussion, while in-season follow up RT_{clin} testing of non-concussed (but often injured) control athletes is associated with a small learning effect. Reliable change calculations indicate that a critical RT_{clin} change score of 0 ms (i.e., interpreting any decline from baseline as indicative of impairment) is 75% sensitive and 68% specific for concussion. These test characteristics compare favorably to most currently available concussion assessment tools, many of which are associated with significantly more time, equipment, and expense than RT_{clin} . Furthermore, RT_{clin} may have even greater utility when used as part of a concussion assessment battery, in concert with a symptom assessment, and clinical cognitive and balance assessments. RT_{clin} , like any concussion assessment tool, cannot diagnose concussion in isolation and must be interpreted by a knowledgeable sports medicine provider in the greater clinical context of the athlete being assessed. The results of this study support the potential use of RT_{clin} as part of a multi-faceted clinical concussion assessment battery.

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Figure 1.
Demonstration of the clinical reaction time device and procedure.

Figure 2. Change in mean clinical reaction time in concussion and control groups. Solid line represents concussion group; dotted line represents controls. Error bars represent standard error.

Figure 3.

Receiver operating characteristic curve for the clinical reaction time test. Open markers represent cut off change scores of 0 and -2 ms, where combined sensitivity and specificity were maximized.

Reliable change cut off values for RT_{clin} at a variety of confidence levels with the number of concussed and control subjects who demonstrated greater decline than the cut off value as well as the corresponding sensitivity and specificity of the RT_{clin} test at each confidence level.

Table 1

Confidence Level	Critical Value*	RT_{clin} cut off value (ms)	Concussed subjects	Control Subjects	Sensitivity	Specificity	Combined Sens + Spec
95%	1.65	30.6	11	2	0.39	0.93	1.32
90%	1.28	21.7	14	4	0.50	0.86	1.36
80%	0.84	11.2	16	6	0.57	0.79	1.36
70%	.052	3.5	18	9	0.64	0.68	1.32
60%	0.25	-3.0	22	11	0.79	0.61	1.40

* Critical values represent the 1-sided z-score associated with each level of confidence.

Table 2
Summary of relevant literature reporting on the test sensitivity and specificity of sport concussion assessment tools.

Reference	Study population	Test admin. time	Test(s) administered	Num. cases	Num. controls	Sensitivity	Specificity	Combined Sens + Spec
Barr & McCrea (2001)^{42,*}	HS & college	immediately	SAC	50	68	94%	76%	1.70
Erlanger et al. (2003)^{46,**}	HS & college	1.96 ± 1.5 d	CRI battery	26	0	77%	n/a	n/a
			Processing speed index			19%		
			Simple RT index			38%		
Iverson et al. (2003)^{45****}	HS & college	< 72 hr	Complex RT index	18	0	54%		
			CRI battery			50%	n/a	n/a
			PS index			11%		
			SRT index			28%		
			CRT index			28%		
McCrea et al. (2005)^{47****}	College	immediately	ImpACT battery	41	56	76%	63%	1.39
			Symptoms			54%	88%	1.42
			Verbal memory			44%	89%	1.33
		2-3 hrs	Visual memory	94	56	42%	89%	1.31
			Reaction time			51%	91%	1.42
			Processing speed			42%	93%	1.35
		2-3 hrs	GSC	94	56	89%	100%	1.89
			SAC			80%	91%	1.71
			BESS			34%	91%	1.25
		1d	GSC	94	56	74%	100%	1.74
			SAC			65%	93%	1.58
			BESS			31%	96%	1.27

Reference	Study population	Test admin. time	Test(s) administered	Num. cases	Num. controls	Sensitivity	Specificity	Combined Sens + Spec
			BESS			16%	93%	1.09
		2d	GSC	****	****	27%	100%	1.27
			SAC			22%	89%	1.11
			BESS			24%	91%	1.15
			NP battery ****			23%	93%	1.16
		3d	GSC	****	****	20%	100%	1.20
			SAC			18%	93%	1.11
			BESS			16%	91%	1.07
		5d	GSC	****	****	10%	100%	1.10
			SAC			18%	93%	1.11
			BESS			10%	93%	1.03
		7d	GSC	****	****	4%	100%	1.04
			SAC			2%	98%	1.00
			BESS			7%	95%	1.02
			NP battery ****			19%	91%	1.10
Schatz et al. (2006) ^{49†}	HS	< 72 h	ImPACT battery	72	66	82%	89%	1.71
Broglio et al. (2007) ^{48††}	College	< 24 h	Concussion symptom inventory	75	0	68%	n/a	n/a
			ImPACT battery	24	0	79%	n/a	n/a
			Symptom inventory			63%		
			Verbal memory			42%		
			Visual memory			21%		

Reference	Study population	Test admin. time	Test(s) administered	Num. cases	Num. controls	Sensitivity	Specificity	Combined Sens + Spec
			Visual motor speed			21%		
			Reaction time			42%		
			Impulse control			4%		
			CRI battery	28	0	78.6	n/a	n/a
			Processing speed index			50%		
			Simple RT index			71%		
			Complex RT index			71%		
			SOT	63	0	62%	n/a	n/a
			Composite balance			37%		
			Somatosensory ratio			37%		
Broglio et al. (2008) ^{††††}	College	< 24 h	Visual ratio			32%		
			Vestibular ratio			24%		
			NP battery ^{†††}	23	0	43.5	n/a	n/a
			SOT battery	63	66	57%	80%	1.38
			Composite balance			44%	91%	1.35
			Somatosensory ratio			11%	91%	1.02
			Visual ratio			18%	89%	1.07
			Vestibular ratio			24%	96%	1.19
			RT _{clin}	28	28	75%	68%	1.43
Eckner et al (2012) ^{††††}	HS & college	< 48 hrs	RT _{clin}	28	28	75%	68%	1.43

* Based on classification of a 1 point decline from baseline as abnormal.

** Regression-based analysis classifying impaired (5th percentile) and borderline (5th – 15th percentile) performance as abnormal.

Based on reliable change index adjusted for practice effects at 80% confidence level.

Regression-based analysis employing a 90% confidence interval for GSC, SAC, and BESS. Individual components of NP battery included HVL T Immediate Memory, HVL T Delayed Recall, HVL T Recognition, Trail Marking Test (Part B), SDMT, Stroop CW Trial, and COWAT; significantly decreased score on 2 or more components was considered abnormal. Attrition rates at each follow-up time point not directly reported.

†

Based on a stepwise discriminant analysis including post-concussion symptom checklist, processing speed composite, visual memory composite, and impulse control composite scores. Results of an analysis including the verbal memory and reaction time composite scores, as well as the sensitivities/specificities associated with the individual test components are not presented.

^{††} Concussion symptom inventory was classified as abnormal when a 1 SD increase above baseline symptom severity and/or duration score was present. Significant declines in ImPACT and CRI scores were interpreted based on the reliable change index score calculations embedded within each program. SOT variables were classified as abnormal when a 1 SD decline from baseline was present. Individual components of the NP battery included the HVLT, TMT (Parts A and B), SDMT, DST, and COWAT; a 1 SD decline in two or more components was considered abnormal.

^{†††} Based on a reliable change index adjusted for practice effects at 75% confidence level.

^{††††} Results presented herein based on reliable change index adjusted for practice effects at 65% confidence level