Evaluating the Recovery Curve for Clinically Assessed Reaction Time After Concussion

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Context: A change in reaction time is one of various clinical measures of neurocognitive function that can be monitored after concussion and has been reported to be among the most sensitive indicators of cognitive impairment.

Objective: To determine the timeline for clinically assessed simple reaction time to return to baseline after a concussion in high school athletes.

Design: Observational study.

Setting: Athletic training room.

Patients or Other Participants: Twenty-one high school-aged volunteers.

Intervention(s): Participants completed 8 trials of the ruler-drop test during each session. Along with baseline measures, a total of 6 additional test sessions were completed over the course of 4 weeks after a concussion (days 3, 7, 10, 14, 21, and 28).

Main Outcome Measure(s): The mean reaction times calculated for all participants from each of the 7 test sessions were analyzed to assess the change in reaction time over the 7 time intervals.

Results: After a concussion and compared with baseline, simple reaction time was, on average, 26 milliseconds slower at 48 to 72 hours postinjury ($P < .001$), almost 18 milliseconds slower on day 7 ($P < .001$), and about 9 milliseconds slower on day 10 ($P < .001$). Simple reaction time did not return to baseline levels until day 14 postinjury.

Conclusions: Clinically assessed simple reaction time appeared to return to baseline levels within a timeframe that mirrors other measures of cognitive performance (approximately 14 days).

Key Words: ruler-drop test, mild traumatic brain injuries, neurocognitive function

Key Points

- The ruler-drop test is an acceptable means of approximating simple reaction time in a clinical setting.
- The ruler-drop test appears to be a useful clinical tool for monitoring recovery from concussion.
- Simple reaction time as assessed in high school athletes using the ruler-drop test appeared to return to baseline between 10 and 14 days postinjury.

One of the tenets of concussion management is to mitigate the risk of reinjury until a patient has fully recovered.¹ A patient's recovery from concussion is typically tracked using clinical tools that are capable of evaluating symptoms, postural control, and neurocognitive function.^{2,3} Because patients demonstrate measureable delays in reaction time after a sport-related concussion,^{4–13} a change in reaction time is one of the various clinical measures of neurocognitive function regularly monitored postinjury and has been reported to be among the most sensitive indicators of cognitive impairment available to practitioners.¹⁴ In fact, a number of authors^{10,13} have reported a protracted recovery for reaction time after injury that persists beyond the resolution of symptoms, indicating that reaction time may be a useful measure for determining if an athlete who reports symptom resolution has indeed recovered fully from a concussion.

A simple and acceptable means of approximating simple reaction time in a clinical setting is to use the ruler-drop test or variants of this technique. For this well-established test, the patient catches a measuring stick that has been dropped and the clinician uses the length or distance the ruler has traveled to assess simple clinical reaction time. Investigators^{6,7} previously suggested that this clinical test of reaction

time could be part of a multifaceted concussion-assessment battery. Research also revealed the ruler-drop test to have acceptable interrater reliability (intraclass correlation coefficient [ICC] = 0.74)¹⁵ and adequate test-retest reliability (ICC range = 0.65–0.86)^{15–18}; the practice effects associated with this test can be minimized by administering at least 1 practice session before establishing a baseline value.¹⁹ Unfortunately, previous authors^{6,7} using the ruler-drop test assessed reaction time at only a single time interval after a concussion (ie, within 48–72 hours of injury), so information regarding a postinjury recovery curve is not available. Therefore, the purpose of my investigation was to determine the timeline for clinically assessed simple reaction time to return to normal after a concussion in high school athletes.

METHODS

Participants

Baseline simple reaction time using the ruler-drop test was assessed in over 800 high school athletes before the start of their athletic season. Although 30 participants sustained a concussion as diagnosed by a physician during the study period, only 21 participants completed the study

Figure 1. Hand position for ruler-drop test.

protocol (20 males, 1 female; age = 16.0 ± 1.1 years; 20 right-hand dominant, 1 left-hand dominant). Volunteers with any existing musculoskeletal condition of the upper extremity that would affect their ability to complete the study were excluded from participation. Approval for the study was obtained from the university institutional review board, and because the data presented here were preexisting, the project met the criteria for exempt status.

Apparatus and Procedure

Participants were required to complete 8 individual trials of the ruler-drop test at 7 time intervals. Along with baseline testing, participants who experienced a concussion were asked to complete testing sessions on days 3, 7, 10, 14, 21, and 28 postinjury; each testing session lasted no more than 10 minutes. The ruler-drop test involves grasping a measuring stick that is 60 cm long and marked in 1-mm increments. For testing, participants sat in a chair while resting the forearm of the dominant hand on the armrest with their fingers suspended below the outer edge of a polyvinylchloride (PVC) pipe (Figure 1). The measuring stick was hidden from view as it was suspended vertically within the PVC pipe, which was 6.0 cm in diameter and open at both the top and bottom. Participants positioned their open hand up against the open lower edge of the pipe so that the 0 (zero) point of the ruler was directly above his or her thumb and index finger. Also, to standardize the starting position of the thumb and fingers during testing, all participants were asked to keep their fingers lined up with the opening of the PVC pipe (approximately 4 cm). This was a critical step because the reaction time assessed in this study consisted of both reaction time and movement time. This means that the time recorded and used in the data analyses consisted of the time it took each participant to initiate the grasping motion (reaction time) as well as the time it took the fingers to come together and grasp the ruler (movement time). Therefore, it was important for the distance between the thumb and index finger to remain constant during all test trials. When the participant was in the ready position, the measuring stick was dropped from inside the pipe at random intervals (between 1 and 5 seconds) to prevent him or her from anticipating the time of

Table 1. Reaction Time Data, ms (Mean $\pm$ SD)

Time	Reaction Time
Baseline	241.6 $\pm$ 23.8
Day	
3	267.6 $\pm$ 23.5
7	259.5 $\pm$ 27.7
10	250.1 $\pm$ 24.7
14	242.4 $\pm$ 22.5
21	240.7 $\pm$ 24.9
28	239.3 $\pm$ 24.2

release. If at any point the participant anticipated the release, the trial was repeated. Once the ruler was released from inside the PVC pipe and visualized, the participant was to catch it as quickly as possible with minimal movement of the hand from the starting position. Although multiple examiners were involved in data collection (10 in total), all received the same training on how to administer the ruler-drop test. The distance the ruler had fallen before it was grasped was measured at the most superior aspect of the participant's thumb and was converted into a reaction time (milliseconds) using the formula for a falling body ($d = \frac{1}{2}gt^2$), where d is distance, g is acceleration due to gravity, and t is time.

Data Analysis

All participants completed 8 trials of the ruler-drop test during each of 7 testing sessions (ie, time intervals). The 2 fastest and 2 slowest times during each test session were eliminated, and the intermediate 4 times were averaged.²⁰ This was done in order to eliminate potential outliers.²⁰ Mean clinical reaction time was assessed for each test session for each participant, and those values were used in the statistical analysis. To determine if there was any significant change in reaction time over the 7 time intervals, repeated-measures analyses of variance were calculated. Post hoc pairwise comparisons (ie, paired-samples t tests) with Bonferroni adjustments were conducted when necessary. The Bonferroni correction is an adjustment to reduce type 1 error and is applied whenever multiple pairwise comparisons are performed. The correction requires that the a priori critical P value (α) be divided by the number of comparisons being made. All statistical analyses were performed using SPSS (version 22.0; IBM Corp, Armonk, NY) with the level of significance for all statistical tests set a priori at $\alpha \leq .05$.

RESULTS

Statistical tests performed on the mean reaction time values from the 7 test sessions (Table 1, Figure 2) revealed a significant main effect for time. The Mauchly test of sphericity was significant, which indicated that the assumption of sphericity had been violated (Mauchly $W = 0.028$, $P \leq .001$). If the assumption of sphericity is violated, the F statistic is rendered invalid, and the risk of type I error increases. To overcome this problem, a correction is applied to the degrees of freedom. In this case, the Huynh-Feldt adjustment for degrees of freedom was applied ($F_{2.9,58.8} = 22.60$, $P < .001$). In this study, 6 pairwise comparison tests were performed. As a result, the new critical P value, calculated by applying the Bonferroni

Figure 2. Individual participant reaction time data.

correction, was .00835. Post hoc tests using the Bonferroni adjustment for multiple pairwise comparisons revealed significant mean reaction time differences between baseline and days 3, 7, and 10 only (Table 2). No other significant differences between test intervals were identified.

DISCUSSION

My purpose was to monitor recovery of simple reaction time performance in high school athletes after concussion. The finding that simple reaction time returned to baseline levels 14 days postconcussion suggests that it follows a recovery pattern similar to other measures of cognitive performance, such as processing speed and verbal memory.^{5,12} The ruler-drop test had previously been reported^{6,7} to be appropriate for inclusion in a multifaceted concussion-assessment battery for injury diagnosis; based on the preliminary findings revealed here, it also appears to be suitable for inclusion among the array of tests generally performed when making return-to-play decisions.

A comparison of the baseline data obtained in this study with those reported in previous studies reveals some inconsistencies in mean baseline reaction time. Specifically, the average baseline reaction time recorded in the current study was between 7 and 48 milliseconds slower than that reported in other studies.^{6,7,11,21} This discrepancy in reaction times is likely related to methodologic differences in the way the ruler-drop test was performed in each study.^{6,7,11,21} Perhaps the most important difference between the variations of the ruler-drop test is related to visualization of the ruler. In the current investigation, the ruler was kept out of sight from the participant, whereas in

previous studies, it was not. The reason for concealing the ruler from view in the current study was to limit or control the participant's urge to anticipate the release of the measuring stick. However, because the height of the opening of the PVC pipe was located below the participant's eye level, the ruler would have likely fallen for a period of time before he or she noticed and grasped it, thereby accounting for the increased (or slower) reaction time. Additionally, there were minor differences among the various forms of the ruler-drop test (eg, in previous studies, the ruler was coated or wrapped with high-friction tape, whereas in this study, it was not), but these methodologic differences are not believed to have had any adverse effects on reaction time.

When compared with baseline values, the mean reaction times obtained at 48 to 72 hours postinjury were fairly consistent and better aligned with those reported in other studies.^{6,7} The average clinical reaction time reported 48 to 72 hours postinjury in previous studies increased to approximately 220 milliseconds,^{6,7} whereas in the current study, reaction time increased to about 267.6 milliseconds on day 3 postconcussion. Although on the surface, the mean reaction time on day 3 in this study appears markedly slower than in previous studies, the absolute difference in mean reaction time between baseline and day 3 essentially amounted to 26 milliseconds. When viewed as a percentage change, the average reaction time at 48 to 72 hours after a concussion in previous studies slowed by 8.4%⁷ to 13.5%⁶ compared with a change of 10.8% in this study.

Although these proportional changes in reaction time at 48 to 72 hours after a concussion appear small, they are nonetheless meaningful differences, particularly if one considers that Eckner et al⁷ proposed a cutoff value of 0 milliseconds when screening an athlete suspected of having a concussion. This was based on their finding that a cutoff score of 0 milliseconds had sensitivity of 0.75 and specificity of 0.68 for the effects of concussion on reaction time. Additionally, the slowed reaction time of the magnitude described in both the current and past studies has been reported to be detrimental.²² In fact, Eckner et al²² noted a strong positive correlation between clinically assessed reaction time and a functional task designed to

Table 2. Post hoc Pairwise Comparisons

Pairwise Comparison	Mean Difference $\pm$ SD, ms	<i>t</i> Statistic	<i>P</i> Value
Baseline to day 3	-26.0 $\pm$ 19.7	-6.05	<.001
Baseline to day 7	-17.9 $\pm$ 18.9	-4.35	<.001
Baseline to day 10	-8.5 $\pm$ 12.4	-3.15	<.001
Baseline to day 14	-0.8 $\pm$ 10.7	-0.33	.749
Baseline to day 21	0.9 $\pm$ 9.5	0.43	.673
Baseline to day 28	2.4 $\pm$ 8.9	1.22	.238

simulate a head-protective response in an athletic environment (ie, raising one's hands in front of the head and face to block an incoming object from striking the face).²² This suggests that returning an athlete to activity when reaction time is impaired (even if the impairment level appears minor) may affect one's ability to use this essential protective strategy.²²

In the past, the efficacy of the ruler-drop test had been assessed only within the initial 48 to 72 hours postinjury^{6,7}; thus, the usefulness of the ruler-drop test for documenting recovery beyond 72 hours had not been established. The present study revealed that reaction time returned to baseline values between days 10 and 14. This finding is within the range reported by authors who have assessed reaction time recovery curves via other methods. For example, Zuckerman et al²³ reported a return to normal reaction time within 7.2 days, whereas others reported ranges of 7 to 14 days¹² or 14 to 21 days.⁵ It should be noted, however, that these previous investigators had relied on computerized neurocognitive tests to assess reaction time, specifically the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). Unfortunately, the ImPACT test does not provide the clinician or researcher with an actual time but rather a composite reaction time score. How comparable these measures are is unknown, as this composite score is calculated from tests that assess visual processing speeds in combination with a choice reaction time task. Thus, the recovery curve of the composite ImPACT score may differ from that demonstrated in simple reaction time tests such as the ruler-drop test.

Although early research on the ruler-drop test revealed acceptable test-retest reliability^{16,17} and adequate criterion validity in collegiate athletes ($r = 0.45$),¹⁸ a recent study by MacDonald et al,¹¹ in which clinical reaction times were compared with results obtained by computerized methods, indicated that reaction times obtained with the ruler-drop test appeared to lack validity in high school-aged participants ($ICC = 0.61$). Although this finding is troubling at first glance, MacDonald et al claimed that the lack of validity identified in their study was likely related to the difference in intrinsic motivation between the assessment methods (ie, clinical versus computerized). More specifically, they suggested that the performance feedback that participants received in real time when using the ruler-drop test (and presumably lacking with computer-based methods) may serve to incentivize or intrinsically motivate the participant¹¹ and, in turn, result in reaction times that are faster and more consistent than those identified via computerized methods.^{11,19,24} This inherent motivation could be considered a benefit or advantage of the ruler-drop test over computerized methods. In addition, the ruler-drop test does not depend on a computer for administration, is more practical to perform in some clinical settings (eg, the athletic training room), and can be conducted more quickly (under 10 minutes) and readily than computerized methods. For these reasons, clinicians should not be quick to discount the potential value of the ruler-drop test, despite preliminary and isolated accounts of poor test validity.

It should also be noted that reliability and validity studies of the ruler-drop test have all been conducted using the more familiar method, which allows for visualization of the ruler during test performance. Although some differences exist between the version of the ruler-drop test used in this

study (no visualization of the ruler) and that used in previous studies (visualization of the ruler), enough similarities may be present between the variations that the validity and reliability scores of both tests can be assumed to be comparable.

All research investigations have limitations that affect the generalizability of the results. The various methodologic limitations of this investigation include the fact that almost all participants were male high school athletes; whether the inclusion of more female participants would have altered the study outcomes is uncertain. Also, several practitioners were involved in the data-collection process. Despite published reports of acceptable interrater reliability associated with the ruler-drop test ($ICC = 0.74$)¹⁵ and the fact that the same individual who collected baseline data on any given person also collected postinjury data on that same person, it is unknown if the use of multiple examiners affected the data. Additionally, concussion history (ie, any previous concussions), learning disabilities, and other comorbidities were neither documented nor controlled in this study, but these elements could affect one's recovery trajectory.³ Finally, clinical reaction time via the ruler-drop test was not compared with other clinical outcomes (eg, symptom scores, postural stability assessments), and so it was not possible to determine if the reaction time recovery curve identified here would have paralleled the recovery curves of those standard clinical measures. Future research on this topic should address these limitations.

In summary, clinically assessed simple reaction time in high school athletes using the ruler-drop test appeared to return to baseline levels between 10 and 14 days postinjury, which is in line with previously published data on the recovery curve of reaction time after concussion. Because the self-reporting of symptoms can be unreliable and neurocognitive deficits may persist beyond symptom resolution, a battery of objective methods is needed to determine recovery from concussion. Based on the results of this investigation, the ruler-drop test appears to be a useful adjunct to the clinician's arsenal of tools for monitoring a patient's recovery from concussion.

ACKNOWLEDGMENTS

I thank Ian Graulich, Sharvettie Frazier, Jennifer Farrant, Anna Griffiths, Tara Mendres, Crista Colaneri, Kayla Wilhide, Kathryn Hill, Morgan Williams, Danielle Blanchard, Samantha Adamo, Barbara Morris, and Whitney Rigaud for their assistance with the study.

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