Investigating the Role of Feedback and Motivation in Clinical Reaction Time Assessment

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Objective: To investigate the influence of performance feedback and motivation during 2 tests of simple visuomotor reaction time (RT).
Design: Cross-sectional, observational study.
Setting: Outpatient academic physiatry clinic.
Participants: Thirty-one healthy adults (mean [SD], 54 ± 15 years).
Methods: Participants completed a clinical test of RT (RT_{clin}) and a computerized test of RT with and without performance feedback (RT_{compFB} and $RT_{compNoFB}$, respectively) in randomly assigned order. They then ranked their degree of motivation during each test. RT_{clin} measured the time required to catch a suspended vertical shaft by hand closure after release of the shaft by the examiner. RT_{compFB} and $RT_{compNoFB}$ both measured the time required to press a computer key in response to a visual cue displayed on a computer monitor. Performance feedback (visual display of the previous trial and summary results) was provided for RT_{compFB}, but not for $RT_{compNoFB}$.
Main Outcome Measurements: Means and standard deviations of RT_{clin}, RT_{compFB}, and $RT_{compNoFB}$ and participants' self-reported motivation on a 5-point Likert scale for each test.
Results: There were significant differences in both the means and standard deviations of RT_{clin}, RT_{compFB}, and $RT_{compNoFB}$ ($F_{2,60} = 81.66$, $P < .0001$; $F_{2,60} = 32.46$, $P < .0001$, respectively), with RT_{clin} being both the fastest and least variable of the RT measurements. RT_{clin} was more strongly correlated with RT_{compFB} ($r = 0.449$, $P = .0011$) than with $RT_{compNoFB}$ ($r = 0.314$, $P = .086$). The participants reported similar levels of motivation between RT_{clin} and RT_{compFB}, both of which were reported to be more motivating than $RT_{compNoFB}$.
Conclusions: The stronger correlation between RT_{clin} and RT_{compFB} as well as the higher reported motivation during RT_{clin} and RT_{compFB} testing suggest that performance feedback is a positive motivating factor that is inherent to RT_{clin} testing. RT_{clin} is a simple, inexpensive technique for measuring RT and appears to be an intrinsically motivating task. This motivation may promote faster, more consistent RT performance compared with currently available computerized programs, which do not typically provide performance feedback.
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INTRODUCTION

Reaction time (RT) is an important performance measure with broad functional relevance that is underused in routine clinical practice. To safely perform basic day-to-day activities, human beings rely on the ability to rapidly react to their environment. RT has been found to be predictive of multiple walking parameters, including gait speed, both on level surfaces [1,2] and on stairs [3]. Furthermore, either an increased or slower RT has been associated with falls in young, healthy persons [4] as well as in older persons in the general population [5-8]. Longer RTs have been associated with an increased risk of motor vehicle accidents in a driving simulator in many clinical populations, including those with depression [9], Huntington disease [10], Alzheimer dementia [11], and obstructive sleep apnea [12]. Complex RT has been found to correlate strongly with on-road driving performance evaluations conducted on elderly drivers in traffic [13]. In addition, color-choice RT was found to be 1 of the 3 visual, cognitive, and motor tests most predictive of driving safety

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The clinical reaction time device discussed in this article was made by the study authors and is not commercially available. The authors have not applied for medical device status with the U.S. Food and Drug Administration for this device.

Disclosure Key can be found on the Table of Contents and at www.pmrjournal.org

The preliminary analysis of these data was presented at the 69th Annual Assembly of the American Academy of Physical Medicine and Rehabilitation, San Diego, CA, November 20-23, 2008.

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during a standardized on-road test of driving performance in elderly drivers [14]. In a large prospective survival study, the mean choice RT and simple RT variability were identified as the best independent predictors of mortality among all of the potential predictor variables studied [15].

In addition to its value as a predictor of performance for a variety of functional tasks, RT is known to be prolonged in many of the populations commonly encountered in physiatric practice. Examples include persons with stroke [16], traumatic brain injury [17,18], dementia [19,20], and polyneuropathy [21,22], and in those experiencing adverse effects from medication [23,24]. The role of RT prolongation in sports-related concussion deserves special mention. Several computerized cognitive assessment tools have been developed to assess cognitive performance in athletes suspected of having sustained a concussion, each of which includes a measure of RT. The Immediate Post-concussion Assessment and Cognitive Test (IMPACT) [25], CogState-Sport [26], and Automated Neuropsychological Assessment Metrics (ANAM) [27] computerized neurocognitive test batteries are 3 of the most popular examples of such programs. In the setting of sports-related concussion, it is now advocated that each athlete's baseline cognitive performance be assessed by using one of these programs during the preseason period so that post-injury comparisons can be made after concussion, with the goal of determining when the athlete has recovered to his or her own individual cognitive baseline [28,29].

Although RT is affected by many disease and injury processes as well as predictive of many outcomes of important functional relevance, it remains underused in routine clinical practice. One important reason for this is that RT assessment typically requires access to a computer equipped with specialized software or to other laboratory-based equipment that is not available in most clinical settings. To address this, we developed a low-technology, inexpensive clinical measure of simple visuomotor RT (RT_{clin}). The technique involves the standardization of a simple experiment commonly performed in high school physics classrooms (eg, Chudler [30]). The apparatus used is a thin, rigid cylinder affixed to a weighted disk that ensures verticality and consistency of hand position. The apparatus is vertically suspended before being released by the examiner and is caught as quickly as possible by the subject being evaluated. The distance that the apparatus falls before being arrested is measured in centimeters and is converted into the clinical RT (RT_{clin}) in milliseconds by using the formula for a free body falling under the influence of gravity.

We have found that RT_{clin} is reliable and valid in a healthy adult population [31] and in a population of collegiate athletes [32,33]. We have demonstrated that RT_{clin} is strongly correlated with the ability to raise the hands to protect the head [34], and we have completed preliminary work that demonstrates that RT_{clin} is prolonged after sports-related concussion compared with baseline testing [35]. While collecting the data for these studies, we have observed that study participants generally appear to be highly motivated to perform their best during RT_{clin} testing. This observation has been especially noticeable in the athletes whom we tested, who typically appear to be much more motivated during RT_{clin} testing than during concurrently administered computerized cognitive test batteries. In the sports concussion setting, it is especially important that the athlete being tested be motivated to give his or her best effort during baseline testing, because the results of this testing will be used as a basis for comparison after concussion. Because athletes know that they will not receive medical clearance for return to play unless their postinjury test performance compares favorably with their baseline test performance, the postinjury test environment is one in which they are typically highly motivated to perform well [36]. If there is a difference in the athlete's level of motivation during baseline and postinjury testing, then this differential motivation may confound the effects of concussion on test performance [36].

Given these observations, we hypothesize that performance feedback in the form of knowledge of results plays an important role in motivating subjects during RT_{clin} testing, because they receive implicit visual feedback during each trial in the form of the distance the apparatus fell before being caught. In contrast, knowledge of results is not typically provided during computerized RT assessment. We further hypothesize that more highly motivated subjects will put forth greater effort during RT testing, which results in improved performance. Therefore, the purpose of this study was to compare participant motivation and performance during RT_{clin} testing with that during computerized RT testing with (RT_{compFB}) and without ($RT_{compNoFB}$) performance feedback in the form of knowledge of the results.

METHODS

Subjects

We recruited 31 adult volunteers (45% women; mean [SD] age, 54 ± 15 years; range, 22-84 years) from the waiting room of an outpatient academic physical medicine and rehabilitation clinic while they waited for friends or relatives to complete their medical appointments. Adults over the age of 18 years, with no history of disease or injury that involved the central or peripheral nervous system or to the dominant upper extremity, were eligible to participate. Participants were excluded if they had corrected visual acuity less than 20/40, were not fluent in English, or in the preceding 30 days had started a new medication or changed the dose of a medication known or suspected to affect the central or peripheral nervous system. All study participants provided written informed consent that was approved by the institutional review board at the first author's institution before participating.

Data Collection

Testing was conducted by a single examiner in a quiet, well-lit room. Each study participant completed RT_{clin}, RT_{compFB}, and $RT_{compNoFB}$ testing in randomly assigned order. Upon completing all 3 tests, the study participants were asked to rate their level of motivation during each RT test by using the following 5-point Likert scale: 1, not motivated; 2, somewhat motivated; 3, moderately motivated; 4, very motivated; 5, extremely motivated.

Measurement of RT_{clin}. RT_{clin} was measured as previously described [31-33,35] by using an 80-cm dowel rod, coated in high-friction tape and marked in 0.5-cm increments, that was embedded into a weighted rubber disk 7.5 cm in diameter, 2.5 cm in height, and 256 g in weight. The participants sat at a table with their dominant forearm resting at the edge of the table surface, such that their hypothenar eminence was positioned at the edge of the table, with their hand in an open "C-shape" position. The examiner suspended the apparatus vertically such that the weighted disk was positioned within the participant's open hand ,with the participants' first and second digits within approximately 0.5 cm of the disk and the top of the disk aligned horizontally with the participants' first and second digits. At predetermined, randomly assigned time intervals that ranged from 2 to 5 seconds, the examiner released the apparatus, and the participant caught it as quickly as possible once it began to fall. The examiner recorded the distance that the apparatus fell, in centimeters, by recording the position of superiormost aspect of the participants' hands after they completely arrested the falling apparatus. The participants were given 4 practice trials before data were collected for 8 trials. If a participant was unsuccessful in catching the apparatus, which resulted in its falling to the floor, then a "drop" trial was recorded, and the examiner continued with the next trial. The fall distances then were converted into RT_{clin} values, in milliseconds, by using the formula for a body falling under the influence of gravity ($g = 1/2\ dt^2$). Means and standard deviations were then calculated for RT_{clin} for each participant.

Measurement of RT_{comp}. RT_{compFB} and $RT_{compNoFB}$ were measured by using a Windows-based (Microsoft Corp, Redmond, WA) personal laptop computer with 2 simple RT tasks programmed in E-Prime (Version 1.1; Psychology Software Tools Inc, Pittsburgh, PA). In both computerized RT tests, the participants sat at the laptop computer with their dominant hand resting comfortably over the keyboard and their gaze fixed on the monitor. At the beginning of each trial a black circle was presented on a white background. The circle then was replaced by a black "X" after a randomly assigned time delay, which ranged from 2 to 5 seconds for each of 4 practice and 40 data acquisition trials. The participants were instructed to depress the space bar as quickly as possible after the visual stimulus changed. The program recorded the elapsed time in milliseconds for each trial and saved these data on the device's hard drive. The 2 computerized RT tasks were identical, except that RT_{compFB} provided performance feedback after each trial, whereas $RT_{compNoFB}$ did not. After each RT_{compFB} trial, the participant's measured RT for that trial, as well as that individual's longest and shortest RTs for the set of trials, were presented. In contrast, after each $RT_{compNoFB}$ trial, the program displayed the following neutrally worded statement: "Get ready now for the next trial." If any irregularities occurred, including depressing the space bar before the stimulus cue or attempting to depress the space bar but the attempt not registered by the computer, then the examiner noted the trial number and that data point was omitted from the final analysis. Means and standard deviations were calculated for RT_{compFB} and $RT_{compNoFB}$ for each participant.

Statistical Analysis

The data for all 3 RT tests appeared right skewed based on visual inspection of data histograms and normal probability plots. Therefore, the data were log transformed to allow the data to more closely approximate normality. The standard deviations of each subject's response were used as a measure of within-subject variability. The means and standard deviations of the various reaction times were evaluated by using repeated-measures analysis of variance. The RT condition was a within-subjects factor to evaluate group differences in the 3 RT conditions. Pearson correlation coefficients were calculated to assess the strength of the relationships between mean RT_{clin}, RT_{compFB} and $RT_{compNoFB}$. The Fisher exact test was used to compare the distribution of self-reported motivation ranking scores among the 3 RT conditions. All statistical analyses were performed by using SAS (version 9.1; SAS Institute Inc, Cary, NC). Excel (version 12.0; Microsoft) was used to generate Figure 1.

RESULTS

Mean RT, as well as RT variability as measured by standard deviation, differed significantly among the 3 tests, with RT_{clin} being the fastest and least variable measure: mean (SD) $RT_{clin} = 234 \pm 28$ ms, mean (SD) $RT_{compFB} = 301 \pm 45$ ms, mean (SD) $RT_{compNoFB} = 327 \pm 52$ ms, $F_{2,60} = 81.66$, $P < .0001$; RT_{clin} variability $= 26 \pm 14$ ms, RT_{compFB} variability $= 80 \pm 54$ ms, $RT_{compNoFB}$ variability $= 88 \pm 60$ ms, $F_{2,60} = 32.46$, $P < .0001$ (Table 1). There was a significant positive correlation between RT_{clin} and RT_{compFB} ($r = 0.449$, $P = .0011$), whereas a weaker, nonsignificant correlation was observed between RT_{clin} and $RT_{compNoFB}$ ($r = 0.314$, $P = .086$).

The distribution of participants' self-reported motivation level during each of the 3 test conditions is illustrated in Figure 1. Participant motivation differed across tests ($P < .0001$). This finding was driven by differential motivation

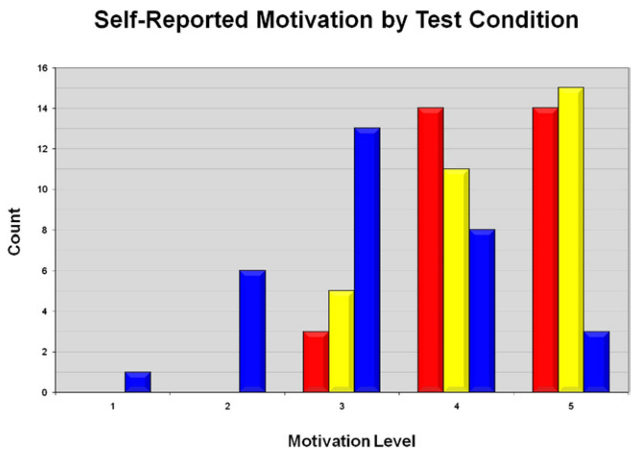

Figure 1. Graphical illustration of participant self-reported motivation during each of the 3 reaction time (RT) test conditions: clinical test of RT (RT_{clin}, red); computerized test of RT with performance feedback (RT_{compFB}, yellow); and computerized test of RT without performance feedback ($RT_{compNoFB}$, blue). 1, not motivated; 2, somewhat motivated; 3, moderately motivated; 4, very motivated; 5, extremely motivated.

between RT_{clin} and $RT_{compNoFB}$ ($P < .0001$) as well as RT_{compFB} and $RT_{compNoFB}$ ($P = .0002$). Participant motivation was similar between RT_{clin} and RT_{compFB} ($P = .6057$). When participants were asked to directly compare their level of motivation between RT_{clin} and RT_{compFB}, 26% rated RT_{clin} as more highly motivating, 52% rated them as equally motivating, and 22% rated RT_{clin} as less highly motivating. When the same comparison was made between RT_{clin} and $RT_{compNoFB}$, 74% rated RT_{clin} as more highly motivating, and 26% rated RT_{clin} and $RT_{compNoFB}$ as equally motivating.

DISCUSSION

RT is typically measured by using computer programs that do not provide performance feedback and are not routinely available in most clinical settings. We developed RT_{clin} to increase the availability of RT testing to clinicians. RT_{clin} can easily be measured during a clinical encounter by using simple low-technology equipment that costs far less than the computer software currently available for RT assessment. The nature of RT_{clin} testing inherently provides the test subject with performance feedback after each trial because the subject can see how far the device fell before being caught. In this study, participants rated RT_{clin} as being similarly motivating to RT_{compFB}, a computerized RT test that provides performance feedback after each trial, and more motivating than $RT_{compNoFB}$, a computerized RT test that does not provide performance feedback. Furthermore, RT_{clin} correlated more strongly with RT_{compFB} than $RT_{compNoFB}$ and was significantly faster and less variable than either of the computerized RT measures. These findings suggest that performance feedback, which is an intrinsic quality of RT_{clin}, improves motivation during RT testing. A high level of motivation on the part of the test taker may contribute to faster, more consistent RT_{clin} results. Previous work [33] that found RT_{clin} to be more consistent over 1 year than an accepted computerized measure of reaction time supports this perspective.

The main argument against providing feedback during RT testing is that feedback "facilitates the learning process" and that "learning should not be reflected in RT measures [37]." The literature evaluating the effect of performance feedback on RT measurement does support the idea that knowledge of results improves RT performance [38-43]. In fact, only partial and even false knowledge of results have been shown to improve RT performance compared with no knowledge of results [38,39,43]. The subjective observation that study participants given knowledge of results appear to be more motivated to perform well than those given no knowledge of results is not unique to our work [40]. When the mechanism by which knowledge of results improves RT was investigated, it was demonstrated that goal setting on the part of the study participants, and not the amount of knowledge of results provided, was responsible for the positive effect of feedback on RT performance [42]. This further supports the concept that knowledge of results works to improve RT performance by increasing participant motivation.

Although there is a theoretical concern that performance feedback may facilitate learning during RT measurement, it is unclear how much RT improvement a study participant can achieve through a learning effect during such a simple, rapid task as RT_{clin}. In this study, the potential learning effect was minimized by randomly assigning the intervals at which both RT tasks required response. Furthermore, the potential learning effect needs to be balanced against the motivating effect that the subjects receive from performance feedback. Motivated participants are more likely to give a consistently high level of effort during RT measurement than unmotivated or bored participants. This is especially important when baseline RT performance is compared with postconcussion

Table 1. *Mean reaction time (RT), and RT variability as measured by standard deviation, for each of the 3 RT test conditions*

RT Test Condition	Mean (SD) RT, ms*	RT Variability, ms†
RT_{clin}	234 ± 28	26 ± 14
RT_{compFB}	301 ± 45	80 ± 54
$RT_{compNoFB}$	327 ± 52	88 ± 60

*$F_{2,60} = 81.66$, $P < .0001$ for test of equality across groups; $F_{1,30} = 93.07$, $P < .0001$ for RT_{clin}-RT_{compFB} comparison; $F_{1,30} = 133.53$, $P < .0001$ for RT_{clin}-$RT_{compNoFB}$ comparison; $F_{1,30} = 11.14$, $P = .0023$ for RT_{compFB}-$RT_{compNoFB}$ comparison.

†$F_{2,60} = 32.46$, $P < .0001$ for equality across groups; $F_{1,30} = 37.36$, $P < .0001$ for RT_{clin}-RT_{compFB} comparison; $F_{1,30} = 75.01$, $P < .0001$ for RT_{clin}-$RT_{compNoFB}$ comparison; $F_{1,30} = 0.52$, $P = .4748$ for RT_{compFB}-$RT_{compNoFB}$ comparison. RT_{clin} = clinical test of RT; RT_{compFB} = computerized test of RT with performance feedback; $RT_{compNoFB}$ = computerized test of RT with out performance feedback.

RT performance in highly motivated athletes, as is increasingly popular in the field of sports concussion management. In this setting, especially, reliable baseline RT data that represent an athlete's best effort are essential to ensure an "apples to apples" comparison between baseline and postinjury data.

The merits of this study are tempered by its limitations. This study was designed with differing numbers of trials between the clinical and computerized RT test protocols. Although this may affect statistical comparisons between the test methods, particularly comparisons of variability, it was done intentionally in an effort to simulate a "real-world" test environment. At least 40 RT trials have been advocated to accurately represent a study subject's actual ability [37], and the most commonly used computer-based RT tests include approximately this number of trials. In contrast, the intention of RT_{clin} is to provide clinicians with a rapid method of measuring RT that is feasible in a busy clinical setting. During pilot reliability and validity testing, we found that analysis of 8 trials yielded results that were statistically similar to analyses that included larger numbers of trials [31]. Therefore, in an effort to limit testing time, we chose to use an RT_{clin} testing protocol composed of 8 trials. A second study limitation is that RT_{clin} is limited by a "ceiling effect," in that RTs longer than 400 ms cannot be recorded. The reason for this is that the 80-cm device falls for only about 400 ms before striking the ground. In practice, it is rare that a study participant is unable to generate a response within 400 ms. This did not occur once during data collection for this study, and it occurred only on 0.1% of simple RT_{clin} trials during our pilot reliability and validity study [31]. If the computerized RT data are truncated at an analogous "ceiling" value of 400 ms, then there are no changes in the results or conclusions. A third limitation of this study is that the Likert scale used to assess study participant motivation during the 3 methods of RT assessment is novel and has not been independently validated as an outcome measure. Yet, it is simple and straightforward, with good face validity, and the associated results were not ambiguous.

CONCLUSION

RT_{clin} is a simple, inexpensive method of measuring RT that provides intrinsic performance feedback, which appears to be a positively motivating factor. Improved subject motivation is likely to promote better effort during testing and results that more consistently represent a subject's true abilities. Although this may be especially beneficial in the setting of pre- and post-RT comparisons, as is commonly used in the field of sport concussion management, a clinical tool capable of consistently measuring a subject's optimal RT may have additional valuable applications in physiatric practice. Further work is warranted to define the potential role of RT_{clin} in such diverse areas as medication adverse effect monitoring, fall risk assessment, driver safety evaluation, and response monitoring during the treatment of sleep apnea and other medical conditions that can impair RT. In conclusion, RT_{clin} is a promising clinical tool that appears to offer advantages over currently available computer-based RT assessment methods, including simplicity, low cost, and intrinsic motivation.

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CME Question

In the study by Eckner et al, which condition for reaction time testing resulted in the highest motivation levels as reported by subjects?

a. computerized visual cue with feedback
b. clinical test of catching dropped rod
c. computerized auditory cue without feedback
d. none of the above

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