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Clinical Reaction-Time Performance Factors in Healthy Collegiate Athletes

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Context: In the absence of baseline testing, normative data may be used to interpret postconcussion scores on the clinical reaction-time test (RT_{clin}). However, to provide normative data, we must understand the performance factors associated with baseline testing.

Objective: To explore performance factors associated with baseline RT_{clin} from among candidate variables representing demographics, medical and concussion history, self-reported symptoms, sleep, and sport-related features.

Design: Cross-sectional study.

Setting: Clinical setting (eg, athletic training room).

Patients or Other Participants: A total of 2584 National Collegiate Athletic Association student-athletes (n = 1206 females [47%], 1377 males [53%], and 1 unreported (<0.1%); mass = 76.7 ± 18.7 kg; height = 176.7 ± 11.3 cm; age = 19.0 ± 1.3 years) from 3 institutions participated in this study as part of the Concussion Assessment, Research and Education Consortium.

Main Outcome Measure(s): Potential performance factors were sex; race; ethnicity; dominant hand; sport type; number of prior concussions; presence of anxiety, learning disability, attention-deficit disorder or attention-deficit/hyperactivity disorder, depression, or migraine headache; self-reported sleep the night before the test; mass; height; age; total number of symptoms; and total symptom burden at baseline. The primary study outcome measure was mean baseline RT_{clin}.

Results: The overall RT_{clin} was 202.0 ± 25.0 milliseconds. Female sex (parameter estimate [B] = 8.6 milliseconds, $P < .001$, Cohen d = 0.54 relative to male sex), black or African American race (B = 5.3 milliseconds, $P = .001$, Cohen d = 0.08 relative to white race), and limited-contact (B = 4.2 milliseconds, $P < .001$, Cohen d = 0.30 relative to contact) or noncontact (B = 5.9 milliseconds, $P < .001$, Cohen d = 0.38 relative to contact) sport participation were associated with slower RT_{clin}. Being taller was associated with a faster RT_{clin}, although this association was weak (B = –0.7 milliseconds, $P < .001$). No other predictors were significant. When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds).

Conclusions: Potentially clinically relevant differences existed in RT_{clin} for sex and sport type. These results provide normative data adjusting for these performance factors.

Key Words: concussion, mild traumatic brain injury, sex, sport type

Key Points

- Performance factors associated with baseline clinical reaction time were sex, race, sport type, and height.
- Both sex and sport type represented clinically relevant differences in clinical reaction time.
- When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds).

Between 1.6 million and 3.8 million sport-related concussions (SRCs) occur annually in the United States.[1] The symptom presentation of sport-related concussion symptoms is highly variable, so a multifaceted and multimodel assessment that supports the clinical examination is the recommended approach for diagnosing SRC and tracking recovery.[2,3] This assessment may include tests of mental status and cognition, oculomotor function, gross sensorimotor function, coordination, gait, vestibular function, balance, and reaction time (RT).[2–4] According to the 5th "Consensus Statement on Concussion in Sport,"[2] baseline testing may be useful but is not necessary for interpreting postinjury scores. In the absence of baseline testing, normative data are used to interpret postinjury scores.[2] For neurocognitive assessments (eg, Immediate Post-Concussion Assessment and Cognitive Testing [ImPACT]), clinical neuropsychologists use demographically adjusted normative data to interpret postinjury scores.[5,6] For other assessments (eg, RT), performance factors, such as demographics, medical and concussion history, self-reported symptoms, sleep, and sport-related features, have not been assessed. Without a comprehensive assessment of these performance factors, it is difficult to provide normative data that will aid in interpreting postinjury scores in the absence of baseline testing.

The measurement of RT typically relies on specialized computer programs as part of the neurocognitive evaluation, which limits its accessibility and translatability in many athletic settings. To enable all health care practitioners to assess simple RT, Eckner et al[7,8] developed a clinically feasible test of simple RT (RT_{clin}), which involved timing how long it took participants to catch a suspended vertical dowel by pinch grip. Clinical RT scores were moderately reliable (intraclass correlation coefficient = 0.645 over a 1-year test-retest interval),[9–11] valid (R = 0.445 compared with computerized RT testing, R = 0.725 compared with a functional head-protective task),[9,10] and sensitive (75%) and specific (68%) in SRC recognition.[12,13] However, performance factors associated with RT_{clin} have received limited attention in the literature. Understanding the performance factors associated with RT_{clin} will allow us to provide normative data that can be used in the absence of baseline testing.

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT Applications, Inc, Coralville, IA) is the most widely used computerized neurocognitive assessment in SRC management and includes RT tests resulting in an RT composite score.[14,15] Performance factors influencing ImPACT RT composite scores in National Collegiate Athletic Association (NCAA) student-athletes include sex, sport type (ie, contact, limited contact, noncontact), and neurodevelopmental and concussion history, although the literature is mixed.[4,16–18] Composite ImPACT scores may differ from RT_{clin} performance as a result of different experimental setups and stimuli. Therefore, the purpose of our study was to explore the effects of performance factors, including demographics (eg, sex), medical (eg, neurodevelopmental) and concussion history, self-reported symptoms, sleep, and sport-related features (eg, level of contact), on baseline RT_{clin} performance. Based on computerized RT performance factors in NCAA student-athletes, we hypothesized that contact-sport athletes and those with neurodevelopmental disorders would have slower RT_{clin}[4,18] but that no differences based on demographic variables[17] or concussion history would be present.[16]

METHODS

Participants

This study was part of the NCAA-Department of Defense Concussion Assessment, Research and Education (CARE) Consortium, a large-scale, multisite study of the natural history of concussion in both sexes and multiple sports.[3] All CARE study participants undergo the Level A assessment battery, which includes demographics and medical history, neurocognitive assessment, neurologic status, postural stability, and symptom evaluation.[3] Selected instruments from the Level B assessments (ie, emerging assessments) are added at the discretion of each performance site.[3] Data from athletes enrolled at all 3 performance sites that elected to use RT_{clin} as part of the Level B assessments were included in the analyses (N = 4782). Because some athletes participated in the CARE Consortium study during more than 1 season, only the first season's baseline results were analyzed (n = 3297). Potential participants were excluded if they did not complete a baseline RT_{clin} assessment (n = 90) or if they were tested with a RT_{clin} protocol consisting of $<$8 data trials (n = 623). Therefore, 2584 participants were included in the final primary analysis (n = 1206 females [47%], n = 1377 males [53%], n = 1 unreported ($<$0.1%); mass = 76.7 ± 18.7 kg; height = 176.7 ± 11.3 cm; age = 19.0 ± 1.3 years; Sport Concussion Assessment Tool [SCAT] total symptom score = 2.2 ± 3.3; SCAT symptom severity score = 3.8 ± 7.1). All study procedures were reviewed by the University of Michigan Institutional Review Board and the US Army Medical Research and Materiel Command Human Research Protection Office, as well as the local institutional review board at each performance site. Participants provided written informed consent before the study began.

Figure 1. Clinical reaction-time test setup.

Clinical RT Testing

The RT_{clin} was performed as previously described (Figure 1).[7–10,12,13,19,20] Briefly, participants were instructed to catch an 80-cm wooden dowel coated in high-friction tape and marked in 0.5-cm increments as quickly as possible. The dowel was embedded in a weighted rubber disk of diameter = 7.5 cm, height = 2.5 cm, and mass = 256 g. The participant sat with the dominant hand positioned at

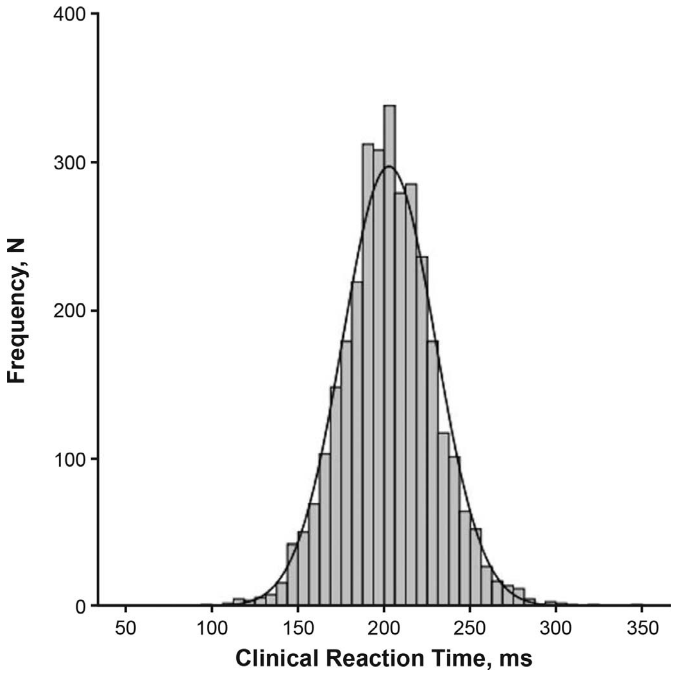

Figure 2. Histogram displaying clinical reaction-time test data suggesting that the data were normally distributed. The black line represents a normal-distribution curve (mean ± SD clinical reaction time = 202.0 ± 25.0 milliseconds).

the edge of the table in an open C-shape position. The examiner initially held the dowel so that the weighted rubber disk was in line with the participant's first and second digits and then released the dowel at predetermined randomly assigned time intervals ranging from 2 to 5 seconds.[7–10,12,13,19,20] The participant caught the dowel as quickly as possible. The distance the apparatus fell was determined from the marked increments on the dowel. The RT_{clin} values were calculated by converting distance to time, in milliseconds, using the formula for a body falling under the influence of gravity ($D = 1/2\ gt^2$). Two practice trials were followed by 8 data-collection trials. If a participant did not catch the dowel, then the examiner recorded the "dropped" trial and the participant continued with the next trial; dropped trials were not replaced. Mean RT_{clin} was then calculated for participants from all successfully completed trials.[7–10,12,13,19,20]

Statistical Analyses

Generalized linear modeling was used to establish performance factors that might be associated with RT_{clin}. Potential performance factors (self-reported) were entered in the following order: sex (*male, female*)[17]; race (*American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or other Pacific Islander, white, multiple races, unknown or not reported*)[21]; ethnicity (*Hispanic or Latino, not Hispanic or Latino, unknown or not reported*)[21]; dominant hand (*right, left, ambidextrous*)[22]; sport type (*contact, limited contact, noncontact*)[4]; number of prior concussions, including both diagnosed and undiagnosed (*0, 1–2, >3*)[16]; presence of anxiety (*yes, no*)[23]; learning disability (*yes, no*)[18,23]; attention-deficit disorder or attention-deficit/ hyperactivity disorder (*yes, no*)[18,23]; depression (*yes, no*)[23]; migraine headache (*yes, no*)[23]; self-reported sleep the night before the test (*<7, 7–9, >9 hours, not reported*) as self-reported on the ImPACT[24]; mass (continuous)[25]; height (continuous)[25]; age (continuous)[22]; total number of SCAT-3 symptoms (continuous)[26]; total SCAT-3 symptom burden (weighted score on the graded symptom checklist, continuous).[26] We fit the generalized linear model for RT_{clin} based on a normal (Gaussian) distribution (Figure 2). Significance was defined a priori as $P < .05$. This analysis was conducted using SPSS (version 24; IBM Corp, Armonk, NY). Effect sizes are included to illustrate the clinical meaningfulness of the findings.

RESULTS

The overall RT_{clin} was 202.0 ± 25.0 milliseconds, with a breakdown by subgroup provided in Table 1. The generalized linear model was a suitable fit to the data (omnibus test: likelihood ratio $\chi^2 = 256.496$, $P < .001$). In this model, sex, race, sport type, and height were the only significant predictors of RT_{clin} (Table 2). Female sex (B = 8.6 milliseconds, $P < .001$, Cohen d = 0.54 relative to male sex), black or African American race (B = 5.3 milliseconds, $P = .001$, Cohen d = 0.08 relative to white race), and limited-contact (B = 4.2 milliseconds, $P < .001$, Cohen d = 0.30 relative to contact) and noncontact (B = 5.9 milliseconds, $P < .001$, Cohen d = 0.38 relative to contact) sport participation were associated with slower RT_{clin} when all other factors were controlled (Table 1). Being taller was associated with a faster RT_{clin}, although this association was weak (B = –0.7 milliseconds, $P < .001$; Table 2). No other predictors were significant (Table 2). When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds; Table 3).

DISCUSSION

Several performance factors may be associated with RT_{clin} in NCAA student-athletes, and adjustments should be made for these performance factors when providing normative baseline data. The purpose of our study was to explore the effects of performance factors, including demographics (eg, sex), medical (eg, neurodevelopmental) and concussion history, self-reported symptoms, sleep, and sport-related features (eg, level of contact), on baseline RT_{clin} performance. Female sex, black or African American race, limited-contact or noncontact-sport participation, and being shorter were associated with slower RT_{clin}. After evaluating effect sizes, we suggest that female sex (Cohen d = 0.54 relative to male sex) and sport type (limited contact: Cohen d = 0.30 relative to contact; noncontact: Cohen d = 0.38 relative to contact) result in potentially clinically relevant differences. We therefore have provided normative data based on these 2 performance factors, which can be considered in the absence of baseline testing.

Sex and sport-contact type were associated with RT_{clin}, whereby males (196 ± 24 milliseconds) had faster RT_{clin} than females (209 ± 24 milliseconds, B = 8.6 milliseconds,

Table 1. Frequency Statistics for Nominal- and Ordinal-Level Predictors

Group	Frequency (%)	Clinical Reaction Time, Mean ± SD	B[a]	Standard Error
Sex				
Female	1206 (46.7)	209.0 ± 24.1	8.616[b]	1.361
Male	1377 (53.3)	195.9 ± 24.2	Ref	Ref
Unreported	1 (<0.1)			
Race				
American Indian or Alaska Native	13 (0.5)	195.7 ± 11.7	−4.848	6.659
Asian	60 (2.3)	208.1 ± 28.8	4.237	3.270
Black or African American	303 (11.7)	203.9 ± 27.0	5.348[b]	1.556
Multiple races	100 (3.9)	200.6 ± 26.5	−0.663	2.532
Native Hawaiian or other Pacific Islander	10 (0.4)	187.4 ± 22.1	−9.805	8.046
Not reported	14 (0.3)	198.2 ± 22.0	0.613	4.498
Unknown	20 (0.8)			
White	2064 (79.9)	201.8 ± 24.6	Ref	Ref
Ethnicity				
Hispanic or Latino	128 (5.0)	201.4 ± 23.0	−2.831	2.749
Not Hispanic or Latino	2211 (85.6)	202.2 ± 25.0	−1.005	1.685
Not reported	98 (0.9)	200.8 ± 26.5	Ref	Ref
Unknown	147 (5.7)			
Dominant hand				
Ambidextrous	83 (3.2)	194.4 ± 24.4	−4.926	2.756
Left	254 (9.8)	202.8 ± 26.8	0.364	1.608
Right	2247 (86.8)	202.2 ± 24.8	Ref	Ref
Sport type				
Noncontact	512 (19.8)	207.5 ± 26.7	5.940[b]	1.386
Limited contact	789 (30.5)	205.2 ± 25.3	4.180[b]	1.167
Contact	1283 (49.7)	197.9 ± 23.4	Ref	Ref
Self-reported number of prior concussions				
0	1889 (73.1)	203.1 ± 25.3	3.001	3.351
1 or 2	628 (24.3)	199.2 ± 24.0	1.353	3.438
3+	58 (2.2)	197.9 ± 2.4	Ref	Ref
Not reported	9 (0.3)			
Medical history				
Anxiety	57 (2.2)	209.0 ± 27.4	5.078	3.431
Attention-deficit disorder or attention-deficit/hyperactivity disorder	202 (7.8)	199.7 ± 24.6	−0.685	1.792
Depression	121 (4.7)	202.5 ± 25.4	−2.195	2.449
Learning disability	93 (3.6)	202.5 ± 25.3	1.577	2.665
Migraine	202 (7.8)	199.7 ± 26.6	−1.851	1.779
Previous night's sleep				
<7 h	779 (30.1)	201.0 ± 24.8	−2.093	1.583
7 to 9 h	1355 (52.4)	202.5 ± 25.5	−0.445	1.467
>9 h	70 (2.7)	202.7 ± 26.1	0.390	3.160
Not reported	380 (14.7)	202.0 ± 23.9	Ref	Ref

Abbreviation: B, parameter estimate; Ref, referent.

[a] Parameter estimates from the generalized linear model are also provided.

[b] Significant predictor.

Cohen d = 0.54) and contact-sport participants (197 ± 23 milliseconds) had faster RT_{clin} than both limited-contact (205 ± 25 milliseconds, B = 4.2 milliseconds, Cohen d = 0.30) and noncontact (207 ± 27 milliseconds, B = 5.9 milliseconds, Cohen d = 0.38) participants. Although these findings differ from those for computerized RT testing,[4,17] RT_{clin} is strongly correlated with a task designed to simulate a natural head-protective response in a sport-related environment and may be a better indicator of functional RT.[19] Males and contact-sport participants may perform better on functional RT testing as a result of faster processing speed and muscle composition, or contact-sport participants may elect to participate in these sports because they have faster RT.

Although statistically, participants of black or African American race (204 ± 27 milliseconds, B = 5.3 milliseconds, Cohen d = 0.08 relative to white race) had slower RT_{clin}, these differences were small and may be clinically insignificant. We aimed to identify common performance factors in RT_{clin} that were consistent with previous RT and neurocognitive assessments, but some performance factors (eg, race) had categories with low frequencies (ie, 80% of all participants were white). This is a limitation, though these data likely represent the NCAA

Table 2. Test of Model Effects for Generalized Linear Model

Source	Type III			Parameter Estimates[a]	
	Wald χ^2 Test Value	df	Significance	B	Standard Error
(Intercept)	319.303	1	<.001	250.536	15.547
Sex	40.075	1	<.001[b]		
Race	16.194	6	.013[b]		
Ethnicity	1.063	2	.588		
Dominant hand	3.304	2	.192		
Sport	22.665	2	<.001[b]		
Previous concussion	2.629	2	.269		
Anxiety	2.190	1	.139		
Learning disability	0.350	1	.554		
Attention-deficit disorder or attention-deficit/hyperactivity disorder	0.146	1	.702		
Depression	0.803	1	.370		
Migraine	1.083	1	.298		
Sleep	2.973	3	.396		
Weight	0.609	1	.435	.105	.020
Height	13.192	1	<.001[b]	−.681	.188
Age	1.608	1	.205	−.487	.384
SCAT Total Symptom Score	0.027	1	.870	−.062	.380
SCAT −3 Symptom Severity Score	0.041	1	.840	.035	.175

Abbreviation: B, parameter estimate; SCAT, Sport Concussion Assessment Tool.

[a] Parameter estimates from the generalized linear model are also provided.

[b] Significant predictor.

athletic population. Considering that only 11.7% of our population reported being African American, these findings may be a result of the small sample size and should be investigated further in the future.

Many factors have been associated with RT in previous work. Age is typically associated with RT. Specifically, RT decreases from infancy into the late 20s and then begins to slow.[27] Considering that the age range of our participants was 17 to 28 years, our sample may have lacked enough variation in age to show this relationship. Similarly, RT increases with fatigue; however, 1 group[28] induced fatigue with 24+ hours of sleep deprivation, and our participants averaged 6.9 ± 1.5 hours of sleep the night before the test. Moreover, fatigue is multifaceted, and as such, we cannot say that the number of hours of sleep reported the night before the test was a measure of fatigue. Although we were able to evaluate a number of potential performance factors, additional factors such as arousal, fasting, alcohol consumption, effort and motivation, personality type, exercise, stimulant medications, and intelligence should be considered in future research.

According to the 5th "Consensus Statement on Concussion in Sport,"[2] baseline testing may be useful but is not necessary to interpret neurocognitive performance after SRC. We have provided normative data adjusting for sex and contact-sport type that can be used in interpreting postinjury scores in the absence of baseline testing. Previous authors[12,13] suggested that a 0-millisecond cutoff score compared with each athlete's own baseline score during the preseason maximized the sensitivity and specificity of SRC diagnosis, so these normative data must be tested with regard to postinjury scores to determine their sensitivity and specificity for SRC management. Therefore, future investigators should determine whether clinicians may consider using these normative data in lieu of individualized baseline measures.

Although we identified several significant performance factors for RT_{clin} and provided normative data for interpreting postinjury scores in the absence of baseline testing, our study had several limitations. Some participants (n = 53) had a RT_{clin} <150 milliseconds, which is physiologically unlikely,[29,30] considering that the stimulus-detection time alone is approximately 120 milliseconds, or the latency of early cortical components of the visual-evoked potentials.[22] These unusually fast RT_{clin} times suggest that participants were likely able to anticipate the apparatus drop. However, they were not statistical outliers, and such an RT_{clin} may occur in the context of typical baseline testing, so these individuals' data were not removed from analyses. To minimize the likelihood of anticipation, examiners were instructed to drop the apparatus at randomly assigned time intervals ranging from 2 to 5 seconds, but some participants may still have been able to predict timing of the drop. Additionally, an athlete's motivation may influence baseline RT_{clin}, though previous research suggested that athletes appeared to be more motivated during RT_{clin} testing than during computerized RT testing.[20] It is certainly possible that an athlete might purposely perform poorly (ie, sandbagging) at preseason baseline testing in an attempt to mask deficits after a suspected concussion. Finally, we recruited only NCAA student-athletes, and thus, these findings may not be applicable to other populations.

Our aim was to explore factors associated with baseline RT_{clin} performance and to provide normative data based on these performance factors. We saw potentially clinically relevant differences in RT_{clin} for sex and contact-sport type, whereby females and noncontact and limited-contact athletes had slower RT_{clin} performance. When adjustments are made for sex and sport type, the following normative data may be considered (mean ± standard deviation): female, noncontact (211.5 ± 25.8 milliseconds), limited

Table 3. Clinical Reaction-Time Test: Normative Data by Sex and Sport Type

Sex	Sport Type	n	Mean ± SD	Standard Error	95% Confidence Interval	Time, milliseconds				
						Above Average[a]	Broadly Normal[b]	Below Average[c]	Poor[d]	Very Poor[e]
Women	Noncontact	340	211.5 ± 25.8	1.3	209.0, 214.1	<186.1	187.1–227.3	228.0–239.7	242.3–272.6	272.6+
	Limited contact	442	212.1 ± 24.3	1.1	209.9, 214.4	<186.9	188.5–228.9	229.6–243.6	245.2–261.1	261.1+
	Contact	424	203.7 ± 21.5	1.2	201.4, 206.0	<182.6	184.0–216.7	217.8–231.7	233.5–250.2	250.2+
Men	Noncontact	171	199.4 ± 26.7	1.8	195.8, 203.0	<169.7	170.8–217.1	218.9–233.5	236.3–250.5	250.5+
	Limited contact	347	196.3 ± 23.9	1.3	193.8, 198.8	<172.8	173.2–210.9	211.6–223.5	225.6–250.7	250.7+
	Contact	859	195.0 ± 23.8	0.8	193.4, 196.6	<170.8	172.3–209.4	210.0–222.4	224.2–244.4	244.4+

[a] Above-average scores occurred in ∼15% of the normative sample. This classification range corresponds to the 85th percentile.
[b] Broadly normal scores occurred in ∼60% of the normative sample. This classification range corresponds to the 25th to 84th percentile.
[c] Below average scores occurred in ∼15% of the normative sample. This classification range corresponds to the 10th to 24th percentile.
[d] Poor scores occurred in ∼8% of the normative sample. This classification range corresponds to the 2nd to 9th percentile.
[e] Very poor scores occurred in fewer than 2% of the normative sample. This classification range corresponds to <2nd percentile.

contact (212.1 ± 24.3 milliseconds), contact (203.7 ± 21.5 milliseconds); male, noncontact (199.4 ± 26.7 milliseconds), limited contact (196.3 ± 23.9 milliseconds), contact (195.0 ± 23.8 milliseconds).

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