Journal of Sports and Performance Vision

Original Research

RELIABILITY AND SEX DIFFERENCES OF CHOICE VISUAL-MOTOR REACTION TIME AND FORCE CHARACTERISTICS OF NECK MUSCLES USING A NOVEL TEST

Takashi Nagai[1,2]*, Nathan D. Schilaty[2,3,4,5], Ryan W. Chang[4], Valerie Keller[4], Sean T. Stiennon[4], Hanwen Wong[4], Michael J. Stuart[2,3], David A. Krause[4]

[1]Military Performance Division, United States Army Research Institute of Environmental Medicine, Natick, MA, USA

[2]Sports Medicine Center, Mayo Clinic, Rochester, MN, USA

[3]Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

[4]Department of Physical Medicine & Rehabilitation, Mayo Clinic, Rochester, MN, USA

[5]Department of Physiology & Biomedical Engineering, Mayo Clinic, Rochester, MN, USA

Author for correspondence: Takashi Nagai: takashi.nagai.civ@mail.mil

Received: 19 May 2021; Accepted: 14 October 2021; Published: 7 April 2022

ABSTRACT

Introduction

Sensorimotor characteristics such as visual-motor reaction time (VMRT), peak force, and rate of force development (RFD) of the neck muscles play an important role in sports-related concussions (SRC). The purpose of this study was to establish reliability and sex differences of neck-specific VMRT and force characteristics of neck muscles using a novel test.

Methods

This is a two-part study. A total of 15 subjects and 49 subjects participated to examine test–retest reliability and sex differences in multidirectional choice VMRT and peak force and RFD values, respectively.

Results

Reliability was moderate for VMRT (Intraclass Correlation Coefficient, ICC = 0.406–0.624) and moderate to excellent for peak force and RFD (ICC = 0.443–0.948). Females had significantly slower VMRT ($P < 0.001$–0.012), while no sex differences were found in peak force and RFD ($P = 0.079$–0.763).

Discussion

Future investigations should incorporate these characteristics during baseline testing and examine if they can be identified as prospective risk factors of SRC.

Keywords: *neck-specific; peak force; rate of force development; sensorimotor; visual-motor reaction time*

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

INTRODUCTION

There are 1.6 to 3.8 million estimated occurrences of sports-related concussions (SRC) among young and athletic individuals.[1] Additionally, there is evidence that females suffer from SRC at a higher rate than their male counterparts.[2] Sex differences in neck biomechanical characteristics (less neck stiffness, higher linear and rotational head acceleration during head impacts in females),[3] reporting behaviors (higher reporting of SRC symptoms in females),[4] and neurocognitive functions (worse visual memory in females)[5] are likely contributing to a higher SRC rate in females. Furthermore, deficits in neck muscular strength in female athletes have gained attention, as one large prospective study reported that every pound increase in neck muscle strength decreased SRC risk by 5%.[6] However, this contention (neck muscle strength deficits as a risk factor of SRC) has been challenged as ice hockey and football athletes with higher neck strength did not mitigate head linear or rotational acceleration experienced during practices or games.[7,8] Additionally, retrospective studies reveal that athletes with a history of SRC had similar neck muscular strength, if not more, when compared to matched athletes without a history of SRC.[9–11] Lastly, a recent prospective study was in agreement with the notion that larger neck circumference (a surrogate measurement of neck strength) was not related to the risk of SRC.[12]

While a role of neck muscle strength in concussion mitigation is uncertain, other factors such as anticipatory activation, faster visual-motor reaction time (VMRT), and quick reaction of neck muscle strength in response to a perturbation are thought to play an important role in reduction of peak linear and angular velocity.[13] A recent computer simulation study revealed that earlier onset of neck muscle activation (40 ms prior to the head impact) could reduce the risk of brain injury.[14] Faster visual processing time could provide critical time for individuals to activate their neck muscles quickly to "brace for impact" and mitigate impact forces to the brain. VMRT can be evaluated with simple testing (i.e., grabbing a falling ruler, clicking a computer key, etc.) or specific testing (i.e., covering face from fast balls[15] or reacting to kick up or down in response to visual cues).[16] Added choices and complexity of tasks can add at least 100 ms to simple VMRT due to additional processing time.[17]

In general, females have shown to exhibit slower simple VMRT compared to their male counterparts although it varies depending on individuals' ages, athletic backgrounds, and testing types or modes.[18] It is believed to be due to greater cross-hemispheric cerebellar connectivity[19] and stronger connectivity between sensory and motor cortices in male brains than female brains, resulting faster reaction time.[20] Because of highly adaptive nature of the brain, VMRT can be improved by visual training.[21] Unfortunately, it can also be deteriorated due to head injuries such as SRC. A recent systematic review and meta-analysis revealed that individuals with SRC exhibited deficits in simple VMRT immediately after the episode and lingering VMRT deficits lasting several months.[22] From a physiological perspective, SRC could disrupt the neural connectivity in the occipital and parietal regions of the brain, resulting in slower visual and visual-spatial processing in individuals with SRC.[23]

In addition to VMRT, another important part of the sensorimotor system is an individual's ability to generate muscular tension (referred to as rate of force development [RFD]). Females generally generate lower neck extension and flexion muscular peak forces and RFD than their male counterparts.[24] However, these sex discrepancies in neck muscular force and RFD values became smaller when normalized to their body mass.[25] In relation to SRC, it is largely unknown if neck RFD characteristics might be negatively affected by SRC. Therefore, more investigations are warranted. Recently, we developed a sensorimotor testing device to measure neck-specific choice VMRT in addition to multidirectional neck strength and RFD. This novel device is designed to be clinically friendly, time efficient (each trial lasts ~10 s), and can collect neck-specific choice VMRT, RFD, and peak force simultaneously

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

under 15 min of test time. Prior to adding this novel testing device to comprehensive SRC management, it is critical to establish methodological variables (reliability, precision, and clinical reference) as well as sex differences.

Therefore, the primary aim of this study was to establish test–retest (1 week apart) reliability, precision, and clinical reference of the novel neck-specific choice VMRT and muscular force characteristics by establishing test–retest *intraclass correlation coefficient* (*ICC*), *standard error of measurements* (*SEM*), and *minimally detectable change with 95% confidence interval* (*MDC95*), respectively. It was hypothesized that test–retest reliability ICC would be moderate (0.41–0.60) to substantial (0.61–0.80)[26] based on previous reliability studies.[27,28] The second aim was to examine sex differences in neck-specific choice VMRT, peak force, and RFD in neck flexion, extension, and right or left lateral flexion directions. For the second aim, it was hypothesized that females would exhibit slower choice VMRT and lower peak force or RFD than their male counterparts based on the previous investigation for knee-specific choice VMRT.[16] These two specific aims addressed in this study could ensure that the novel device and data could be used for baseline screening test or post-SRC testing to monitor recovery progress and to assist with comprehensive return-to-sport decision-making in future investigations.

METHODS

Research design and participants

This study was reviewed and approved by the Institutional Human Ethics Review Board (19-009042 and 17-006025). For both aims, inclusion criteria were between ages 14 and 30, physically active, and free from any neck pain or other neurological, musculoskeletal, and/or medical conditions. Exclusion criteria were mental or learning disability, current signs or symptoms of any musculoskeletal injury, current neck or back pain or concussions, and any surgeries or diagnosed medical conditions that affect balance, sensation, vision, or hearing. For the first aim, test–retest reliability studies require a minimum of 15 subjects to achieve ICC = 0.4–0.9 with power (1–β) = 80% and alpha (α) = 0.05.[29] Therefore, a total of 15 healthy subjects (10 females and 5 males, age: 24.5 ± 2.1 years, height: 168.1 ± 7.4 cm, weight: 70.6 ± 11.3 kg) were recruited to participate in laboratory testing twice (1 week apart). Most subjects were physically active and were students in the physical therapy program. For the second aim, an estimated sample size was determined based on the previous data[25] on sex differences on neck muscular peak force and RFD (average sample size estimate: n = 18 [range from 12 to 23]). Neck-specific choice VMRT has not been investigated in the study[25]; therefore, results on sex differences using the knee-specific choice VMRT were used to estimate sample size.[16] *A priori* power analysis using G*Power software (version 3.1.9.2, Dusseldorf, Germany) revealed that a minimum of 18 subjects per group would be required to meet the following statistical parameters, 1–β = 0.8, α = 0.05, and Effect Size Cohen's d = 0.853, for an independent t-test design. A total of 49 healthy subjects (21 females and 28 males) from local high schools, colleges, and professional schools participated in the Aim 2 of the study. All participants were physically active at various competitive levels. Descriptive statistics and sex differences in demographics are provided in Table 1.

Instrumentation

A novel multidirectional neck isometric dynamometer with a six degree-of-freedom load cell (45E15; JR3, Woodland, CA, USA) was used in this investigation. The load cell interfaced with a baseball

TABLE 1 Demographics

	Female AVE ± SD	Male AVE ± SD	P
Age, years	19.3 ± 4.4	18.3 ± 4.1	0.401
Height, cm	167.2 ± 7.1	176.0 ± 7.9	<0.001*
Weight, kg	62.1 ± 7.6	73.6 ± 12.2	0.005*

**Represents significant sex differences (P < 0.05).*

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

helmet (Rawlings Coolflo Batting Helmet, Rawlings, St. Louis, MO, USA) with an aluminum plate. Three different helmet sizes (Tball, Junior, and Senior) were used to ensure tight fit to each participant. The load cell was connected to a data acquisition device (USB-1608G; Measurement Computing, Norton, MA, USA) and a USB isolator (UHR402; Advantech, Milpitas, CA, USA). A monitor was placed in front of the participants for visual cues and visual feedback. Customized LabVIEW software (National Instruments, Austin, TX) was used to trigger a visual cue ("FORWARD," "BACKWARD," "RIGHT," or "LEFT" arrow) at random intervals between 3 and 10 s after the initiation of each trial. Trigger time and force output were sampled at 1000 Hz.

Procedures

To conduct the test, subjects sat on a chair with an adjustable harness to secure their trunk; they were provided a swim cap (for hygienic purposes) which was donned prior to fitment of the helmet (Figure 1). Verbal instructions and explanations of all testing procedures were provided to the subjects. They were instructed to avoid using their trunk muscles (and this was diminished by the tightened harnesses), grasping the device with their hands, or pushing against the device with their feet. During practice trials, subjects were asked to push to each of four directions (flexion, extension, and left or right lateral flexion directions) at 50% effort and then at 100% effort as warm-up to check for their comfort and any loose belts and harnesses. Next, subjects practiced three trials performing randomized directions for VMRT. Subjects were instructed to push to different directions (flexion, extension, and right or left lateral flexion) as fast and hard as they could as soon as the visual cue ("FORWARD," "BACKWARD," "RIGHT," and "LEFT" arrow) appeared on the monitor, respectively (Figure 1). Subjects continued pushing as hard as they could for at least 3 s.

Data processing

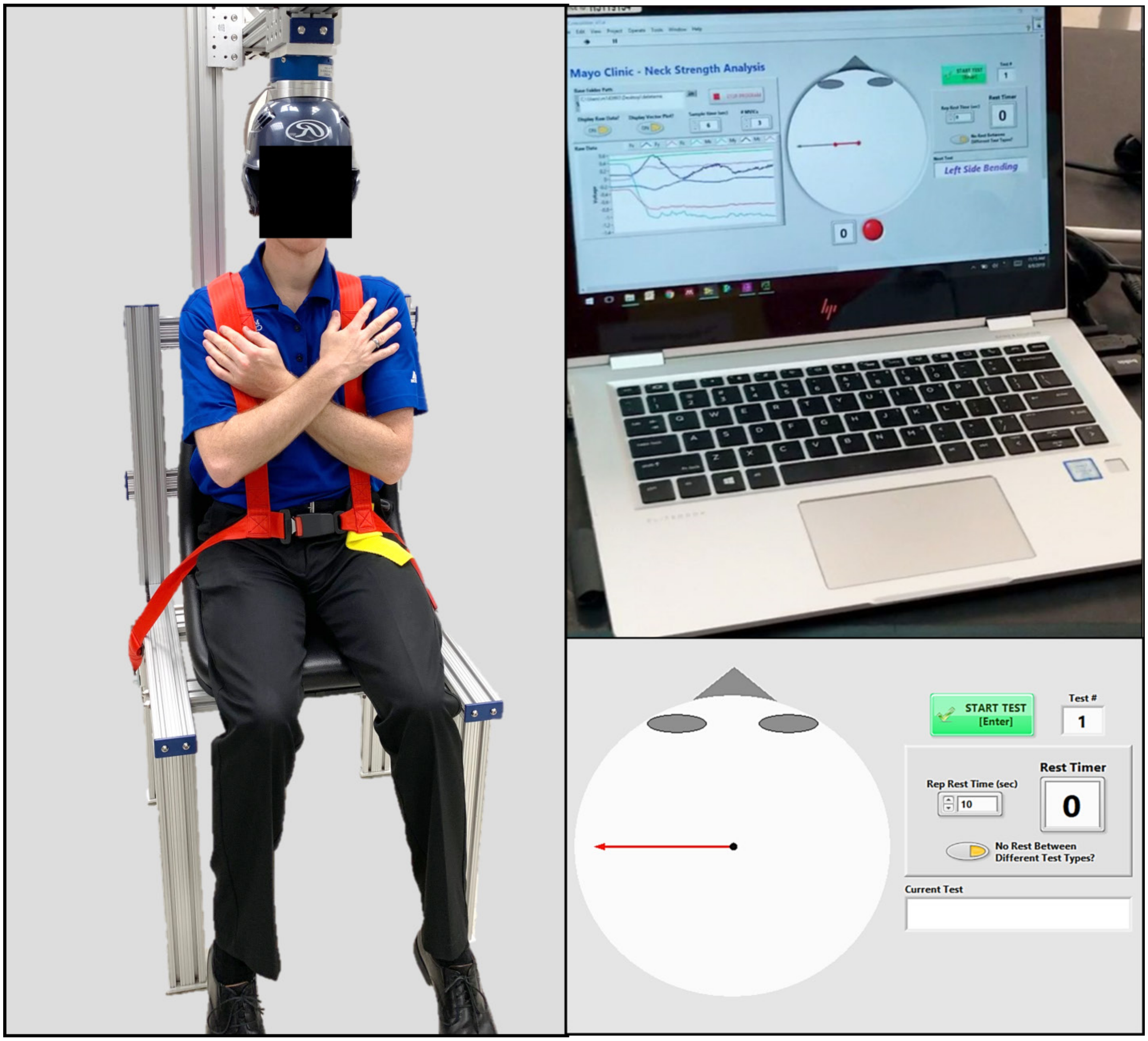
Each trial was visually inspected using a time–force plot (Figure 2). The onset of the visual trigger was automatically recorded in a spreadsheet output. The time between the onset of the visual trigger and a force greater than 5 N were used to calculate choice VMRT in milliseconds (ms). From the time point of stimulus reaction (>5 N), muscular force was seen to rapidly increase to reach the peak within a second or two. Forces at 50 ms, 100 ms, 150 ms, and 200 ms were identified in the force–time plot (Figure 2). Then, RFD was calculated by dividing the forces (at 50 ms, 100 ms, 150 ms, and 200 ms) by each time point (0–50 ms: 0.05 s, 0–100 ms: 0.1 s, 0–150 ms: 0.15s, 0–200 ms: 0.2 s) for each trial, respectively. Lastly, after the values for the three trials were averaged, the peak force in Newtons (N) and RFD (N/s) was normalized to body mass (N/kg and N/s*kg, respectively). In summary, multidirectional neck-specific choice VMRT, peak force, and four RFD variables (RFD50, RFD100, RFD150, RFD200) on each direction were analyzed in this study.

Statistical analyses

Test–retest reliability and precision were analyzed using ICC model 3.1 and SEM, respectively. ICC values were classified as moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect agreement (0.81–0.99).[26] SEM was calculated by multiplying a pooled standard deviation and $\sqrt{(1\text{–ICC})^2}$. SEM is estimated from the standard deviation of a sample of scores at baseline and test–retest reliability index of the measurement instrument or test employed and represents the magnitude of expected error associated with the procedures.[30] MDC95 was calculated by multiplying SEM values by $1.96*\sqrt{2}$ to provide clinical references for each variable. MDC95 is similar to statistical significance and represents the minimum amount of change that needs to be observed to be considered for a real change, or a change to which the contribution of real modifications in performance is likely to be greater than that of random measurement error.[30] ICC does not have any unit, while SEM and MDC95 share the same unit of each dependent variable. For sex differences, each dependent variable (neck-specific choice

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

FIG. 1 Neck-specific choice visual-motor reaction time device, subject set-up, and visual feedback. A red arrow will appear to any one of four directions (flexion, extension, and right or left lateral flexion) randomly (between 3 and 10 s from the beginning of trial).



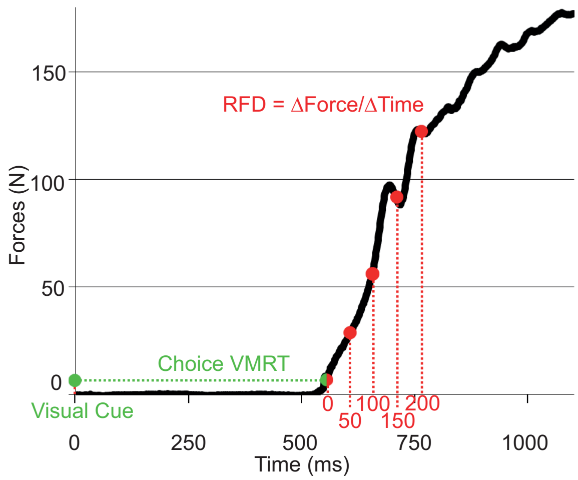
VMRT, peak force, and RFD50/100/150/200) was screened for normality with Shapiro–Wilk tests. Based on the normality, either independent t-tests or Mann–Whitney U tests were performed to compare between sexes for each dependent variable. All analyses were completed using the IBM SPSS Statistical Version 25 (IBM Corp., Armonk, NY). Significance was set *a priori* at $P < 0.05$.

RESULTS

For reliability and precision, VMRT was moderately reliable (ICC = 0.406–0.624), while the peak force and RFD measurements were moderate to almost perfect agreement (ICC = 0.443–0.948). For precision values and clinical references, SEM and MDC are described in Table 2. Descriptive statistics

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

FIG. 2 Force–Time plot during choice visual-motor reaction time (VMRT) test. Choice VMRT is calculated as time between the visual cue and the initiation of the force production (>5 N). RFD at 50 ms, 100 ms, 150 ms, and 200 ms (red colored numbers) is calculated as the change of force over the change of time (from the initiation of the force production [>5 N]: red colored 0 ms).



(averages and standard deviations) for each variable and sex differences are described in Table 3. Females had significantly slower choice VMRT in all four directions ($P < 0.001$–0.012), while there were no sex differences in normalized peak forces ($P = 0.136$–0.799) and RFD. For RFD variables, females had lower normalized RFD values; however, there were no statistically significant sex differences for all four directions ($P = 0.079$–0.763).

DISCUSSION

This study establishes the reliability, precision, and clinical references for multidirectional neck-_ specific choice VMRT, neck muscular strength, and RFD. The first hypothesis was supported as moderate to substantial ICC values were found. The current ICC values for VMRT (ICC = 0.41–0.62) were similar to the ICC values from a previous study using a Ruler Drop Test (ICC = 0.43–0.73) and

TABLE 2 Test–retest reliability (*intraclass correlation coefficient model 3.1: ICC*), precision (*standard error of measurement: SEM*), and clinical references (*minimal detectable change with 95% confidence interval: MDC95*) on reaction time and force characteristics

VMRT	**ICC**	**SEM**	**MDC95**
Flexion	0.624	27.0 ms	74.8 ms
Extension	0.536	34.9 ms	96.8 ms
R. Lat. flexion	0.466	35.7 ms	98.9 ms
L. Lat. flexion	0.406	31.0 ms	85.9 ms
Peak force	**ICC**	**SEM**	**MDC95**
Flexion	0.697	0.18 N/kg	0.50 N/kg
Extension	0.555	0.35 N/kg	0.96 N/kg
R. Lat. flexion	0.684	0.22 N/kg	0.62 N/kg
L. Lat. flexion	0.804	0.21 N/kg	0.58 N/kg
RFD50	**ICC**	**SEM**	**MDC95**
Flexion	0.443	1.59 N/s*kg	4.41 N/s*kg
Extension	0.834	1.29 N/s*kg	3.57 N/s*kg
R. Lat. flexion	0.804	1.27 N/s*kg	3.52 N/s*kg
L. Lat. flexion	0.948	0.88 N/s*kg	2.43 N/s*kg
RFD100	**ICC**	**SEM**	**MDC95**
Flexion	0.777	1.32 N/s*kg	3.67 N/s*kg
Extension	0.744	2.60 N/s*kg	7.20 N/s*kg
R. Lat. flexion	0.886	1.27 N/s*kg	3.52 N/s*kg
L. Lat. flexion	0.928	1.16 N/s*kg	3.23 N/s*kg
RFD150	**ICC**	**SEM**	**MDC95**
Flexion	0.669	1.08 N/s*kg	2.98 N/s*kg
Extension	0.685	2.29 N/s*kg	6.34 N/s*kg
R. Lat. flexion	0.860	0.94 N/s*kg	2.61 N/s*kg
L. Lat. flexion	0.783	1.23 N/s*kg	3.42 N/s*kg
RFD200	**ICC**	**SEM**	**MDC95**
Flexion	0.754	0.60 N/s*kg	1.67 N/s*kg
Extension	0.699	1.34 N/s*kg	3.73 N/s*kg
R. Lat. flexion	0.734	0.76 N/s*kg	2.10 N/s*kg
L. Lat. flexion	0.561	1.05 N/s*kg	2.91 N/s*kg

VMRT: Visual-Motor Reaction Time; PF: Peak Force; RFD: Rate of Force Development; R. Lat. Flexion: Right Lateral Flexion; L. Lat. Flexion: Left Lateral Flexion; RFD50, RFD100, RFD150, and RFD200: Rate of Force Development at each time points 0–50 ms, 0–100 ms, 0–150 ms, and 0–200 ms, respectively.

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

TABLE 3 Descriptive statistics and sex differences in reaction time, peak force, and rate of force development

VMRT	**Female AVE ± SD**	**Male AVE ± SD**	**P**
Flexion	561.9 ± 104.4 ms	460.2 ± 82.9 ms	<0.001*
Extension	540.2 ± 77.7 ms	451.5 ± 70.9 ms	<0.001*
R. Lat. flexion	481.2 ± 79.2 ms	419.4 ± 63.8 ms	0.012*
L. Lat. flexion	482.0 ± 80.0 ms	418.5 ± 63.6 ms	0.004*
Peak force	**AVE ± SD**	**AVE ± SD**	**P**
Flexion	1.36 ± 0.38 N/kg	1.52 ± 0.57 N/kg	0.271
Extension	1.91 ± 0.66 N/kg	2.26 ± 0.89 N/kg	0.136
R. Lat. flexion	1.55 ± 0.43 N/kg	1.69 ± 0.56 N/kg	0.322
L. Lat. flexion	1.63 ± 0.49 N/kg	1.67 ± 0.61 N/kg	0.799
RFD50	**AVE ± SD**	**AVE ± SD**	**P**
Flexion,	4.04 ± 1.77 N/s*kg	5.60 ± 5.38 N/s*kg	0.201
Extension	4.89 ± 2.49 N/s*kg	6.71 ± 5.09 N/s*kg	0.083
R. Lat. flexion	5.54 ± 2.60 N/s*kg	6.09 ± 3.00 N/s*kg	0.473
L. Lat. flexion	5.26 ± 2.44 N/s*kg	5.95 ± 3.72 N/s*kg	0.763
RFD100	**AVE ± SD**	**AVE ± SD**	**P**
Flexion	4.57 ± 2.01 N/s*kg	6.53 ± 4.07 N/s*kg	0.079
Extension	6.55 ± 4.28 N/s*kg	7.97 ± 4.85 N/s*kg	0.216
R. Lat. flexion	6.68 ± 3.85 N/s*kg	7.44 ± 3.82 N/s*kg	0.377
L. Lat. flexion	6.43 ± 3.85 N/s*kg	7.62 ± 4.62 N/s*kg	0.377
RFD150	**AVE ± SD**	**AVE ± SD**	**P**
Flexion	4.25 ± 1.69 N/s*kg	5.88 ± 3.34 N/s*kg	0.083
Extension	6.25 ± 3.42 N/s*kg	8.11 ± 4.23 N/s*kg	0.103
R. Lat. flexion	5.92 ± 2.55 N/s*kg	6.69 ± 3.04 N/s*kg	0.355
L. Lat. flexion	5.93 ± 2.67 N/s*kg	6.68 ± 3.30 N/s*kg	0.401
RFD200	**AVE ± SD**	**AVE ± SD**	**P**
Flexion	3.79 ± 1.34 N/s*kg	4.53 ± 1.76 N/s*kg	0.117
Extension	5.56 ± 2.31 N/s*kg	7.01 ± 3.10 N/s*kg	0.081
R. Lat. flexion	4.84 ± 1.62 N/s*kg	5.36 ± 2.07 N/s*kg	0.349
L. Lat. flexion	4.91 ± 1.67 N/s*kg	5.13 ± 2.08 N/s*kg	0.696

**Represents significant sex differences (P < 0.05). VMRT: Visual-Motor Reaction Time; RFD50, RFD100, RFD150, and RFD200: Rate of Force Development at each time points 0–50 ms, 0–100 ms, 0–150 ms, and 0–200 ms, respectively.*

a computer-based reaction test (ICC = 0.55–0.79).[27] The current reliability for normalized peak force (ICC = 0.56–0.80) and RFD (ICC = 0.44–0.93) was similar to our previous reliability for normalized peak force (ICC = 0.67–0.84) and RFD (ICC = 0.66–0.85) for healthy high school athletes.[25] Other studies have reported similar or higher ICC on peak force (ICC = 0.63–0.97)[31,32] and RFD (ICC = 0.83–0.99).[13,33] In addition to ICC values, this study has provided precision and clinical references using the current novel testing procedures and variables. Clinical references (MDC95) for multidirectional neck muscular peak force, RFD, and neck-specific choice VMRT were 0.5–0.96 N/kg, 1.67–7.2 N/s*kg,

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

and 74.8–98.9 ms, respectively. Based on the current methodology, MDC95 values as clinical reference provided conservative values than statistical significance. In other words, choice VMRT in the flexion direction was the only variable that met both clinical (MDC95 = 74.8 ms) and statistical significance ($P < 0.001$). Researchers and clinicians can utilize these MDC95 values in their practice to see effects of preventive interventions or rehabilitation.

The second hypothesis was partially supported as sex differences were observed in neck-specific choice VMRT, while normalized peak force and RFD did not show significant sex differences. Neck-specific choice VMRT values (481–562 ms) in this study were similar to computer-based (ImPACT®) reaction time (582–598 ms) but slower than a simple ruler drop test values (190–199 ms).[34] Normalized peak force values in this study (1.4–2.3 N/kg) were similar, but not as high as our previous neck strength values for high school soccer athletes (1.6–3.2 N/kg) and high school football athletes (1.7–3.0 N/kg).[10,25] For neck RFD, the current RFD50/100/150/200 values (3.8–8.1 N/s*kg) were higher than the previous neck RFD to 90% of the peak force for soccer athletes (1.7–4.6 N/s*kg) and football athletes (1.8–4.1 N/s*kg).[10,25]

Simple VMRT has been a part of comprehensive SRC clinical evaluation and management. Among VMRT tests, reaction time measured using a computer-based software, ImPACT®, is the most widely utilized and could be used to identify deficits in VMRT after SRC.[22] Deficits in simple VMRT are reported to be the largest in the acute phase of SRC (within 72 h) with deficits lasting up to 59 days post SRC.[22] The magnitude of deficits in simple VMRT after SRC is on an average 58 ms in ImPACT® testing[35] and 30 ms with the simple ruler drop test[36], although VMRT performance can vary depending on age, sex, sports, types of tests, setting, etc. This study, however, was aimed to establish the reliability and sex differences in healthy individuals without history of SRC. In literature, it is generally accepted that females exhibit slower VMRT than males although athletic background in fast-paced sports and vehicle driving experiences has shown to improve VMRT and reduce the magnitude of sex differences.[18] Among athletes, there were mixed results on sex differences in reaction time. For example, female soccer athletes scored slower ImPACT® reaction time[37]; On the contrary, there were reports that male athletes scored slower reaction time.[38,39] The current results on sex differences in neck-specific choice VMRT agree with the former. Again, because individuals' age and athletic background could influence VMRT, future studies should control these confounding factors.

In our recent investigation on knee-specific choice VMRT, among high school basketball athletes, female athletes exhibited slower reaction time than their male athletes.[16] Interestingly, the magnitude of sex differences in our previous study (average 99 ms) was 26% slower than the current results during neck-specific VMRT (average 79 ms). Additionally, likely due to the distance from the motor cortex of the brain, knee-specific VMRT values (females: 562 ms, males: 462 ms) were slightly slower (5.7–8.9%) than neck-specific VMRT values (females: 516 ms, males: 437 ms) in both sexes. While it is beyond the scope of the current investigation, these observations from our two investigations support the notion that VMRT could be joint-, direction, or muscle-specific and open discussions whether baseline testing should focus more on neck-specific VMRT instead of generic VMRT such as a ruler drop test or computer clicking.

Peak force and Rate of force development

There were no sex differences in the current study although males consistently had higher neck strength ($P = 0.136–0.799$) and RFD ($P = 0.079–0.763$). This finding was contrary to the hypothesis. Most studies report that males have higher neck muscular strength[13,24,40,41]; however, the magnitude of sex difference becomes smaller or reversed when normalized values are used.[25,42,43]. In a previous study on sex differences in neck muscular RFD, males had higher RFD than females.[24] As stated earlier, the current neck peak force values were smaller

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

than the previous studies, likely due to differences in subjects' athletic background. Additionally, new VMRT function and testing procedures might have influenced the peak force and RFD. For example, during the earlier studies, subjects focused mainly on their neck strength in the predetermined directions with verbal countdown. Additionally, subjects could also see how hard they were pushing in the time–force plot. Contrarily, in the current investigation, examiners remained silent until subjects responded to the visual cue, and time–force plot was not displayed. Both verbal encouragement[44] and visual feedback[45] have shown to increase force production by 5–8%. These two factors would likely explain the diminished values in the peak force and a lack of sex differences.

Despite diminished peak force, the current RFD results were higher (males: 4.5–8.0 N/s*kg and females: 3.8–6.6 N/s*kg) compared to our previous findings (males: 2.2–4.6 N/s*kg and females: 1.4–3.1 N/s*kg).[25] The main difference between the studies was the time intervals for RFD. The earlier study utilized the time to reach 90% peak force while this study utilized much earlier onset: 50 ms, 100 ms, 150 ms, and 200 ms. The rationale to include earlier time intervals was that RFD50/100 represents the neural factors to recruit motor units and muscle fiber composition, and RFD150/200 relates to the ability to produce maximum force.[46] The earlier time intervals produced significant changes in force (thus higher RFD) than later time intervals (at 90% peak) (Figure 2). Based on our previous and current results, regardless of the differences in the time intervals, no sex difference was observed. There were trends of sex RFD differences in the flexion and extension directions ($P = 0.079–0.083$). Post-hoc power analysis revealed that ~40 subjects per group would be needed to reach statistical significance, thus this study may be underpowered.

A mixed role of neck muscular peak force or strength as a risk factor of SRC has been reported. In addition to physiological characteristics, reporting behaviors might be different between sexes (female athletes report SRC while male athletes might try to "shake it off").[4,47] Additionally, athletes with SRC might be more aggressive in their playing style, predisposing them to SRC as well as other musculoskeletal injuries.[48] Interestingly, our previous study revealed that high school football athletes with a history of SRC had significantly higher neck muscular strength (3.5–16.7%) and RFD (21–70%) when compared to matched control athletes.[10] In our recent prospective study, the Division III college football athletes and wrestlers, who later suffered SRC in the season (n = 12), exhibited significantly higher neck strength (12.6–21.1%) and RFD (14.6–43.3%) than the nonconcussed athletes (n = 87). The earlier studies prompted us to investigate the temporal characteristics of the neck-specific sensorimotor system and added the neck-specific choice VMRT. Based on the current results, female athletes, and individuals with a history or current episode of SRC should explore intervention strategies to improve VMRT. For example, effects of vision training could be incorporated to preventive and rehabilitation exercise as a part of SRC management strategy.[49,50]

The current investigation has a few limitations. Firstly, athletic background and age of participants were not strictly matched. As a piloting study, this study was to explore reliability and sex differences. However, future investigations can focus more on specific age (high school, college, or professionals), sport types, and competition levels (recreational versus competitive). Secondly, additional neck neuromusculoskeletal characteristics such as range of motion, forward head posture, muscular endurance, muscle tone or stiffness, and proprioception were not collected. Inclusion of these common clinical tests might add insights and could be used to establish relationship among these characteristics. Thirdly, the current results and sex differences in VMRT do not mean that those individuals are at higher risk of SRC. Prospective studies would be needed to establish such relationships. For a rehabilitation perspective, repeated testing of neck-specific VMRT after SRC would be needed to add clinical importance.

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

CONCLUSION

This study examined neck-specific VMRT in addition to traditional neck muscular characteristics (peak force and RFD) and investigated reliability and sex differences. Based on the current results, females might be at higher risk in part due to delayed neck-specific choice VMRT. Future studies should follow participants longitudinally to validate this notion. Intervention strategies to improve VMRT should be investigated as well. This novel device and associated metrics may provide baseline criteria for screening as well as a reference to determine effects of SRC rehabilitation and management.

CONFLICT OF INTEREST

None declared.

ACKNOWLEDGMENTS

Funding provided by the Mayo Clinic Ice Hockey Research Group and NIH awards L30AR070273 and K12HD065987.

DISCLAIMER

The views expressed in this manuscript are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

REFERENCES

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: A brief overview. J Head Trauma Rehabil. 2006;21(5):375–8. http://dx.doi.org/10.1097/00001199-200609000-00001
2. Covassin T, Moran R, Elbin RJ. Sex differences in reported concussion injury rates and time loss from participation: An update of the National Collegiate Athletic Association Injury Surveillance Program from 2004–2005 through 2008–2009. J Athl Train. 2016;51(3):189–94. http://dx.doi.org/10.4085/1062-6050-51.3.05
3. Eckner JT, O'Connor KL, Broglio SP, Ashton-Miller JA. Comparison of head impact exposure between male and female high school ice hockey athletes. Am J Sports Med. 2018;46(9):2253–62. http://dx.doi.org/10.1177/0363546518777244
4. Wallace J, Covassin T, Beidler E. Sex differences in high school athletes' knowledge of sport-related concussion symptoms and reporting behaviors. J Athl Train. 2017;52(7):682–8. http://dx.doi.org/10.4085/1062-6050-52.3.06
5. Covassin T, Swanik CB, Sachs M, Kendrick Z, Schatz P, Zillmer E, et al. Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. Br J Sports Med. 2006;40(11):923–7; discussion 927. http://dx.doi.org/10.1136/bjsm.2006.029496
6. Collins CL, Fletcher EN, Fields SK, Kluchurosky L, Rohrkemper MK, Comstock RD, et al. Neck strength: A protective factor reducing risk for concussion in high school sports. J Prim Prev. 2014;35(5):309–19. http://dx.doi.org/10.1007/s10935-014-0355-2
7. Mihalik JP, Guskiewicz KM, Marshall SW, Greenwald RM, Blackburn JT, Cantu RC. Does cervical muscle strength in youth ice hockey players affect head impact biomechanics? Clin J Sport Med. 2011;21(5):416–21. http://dx.doi.org/10.1097/JSM.0B013E31822C8A5C
8. Schmidt JD, Guskiewicz KM, Blackburn JT, Mihalik JP, Siegmund GP, Marshall SW. The influence of cervical muscle characteristics on head impact biomechanics in football. Am J Sports Med. 2014;42(9):2056–66. http://dx.doi.org/10.1177/0363546514536685
9. Black SR. Neck strength and concussion in NCAA division I football. Lubbock, TX: Exercise and Sport Science, Texas Tech University; 2007.
10. Nagai T, Ueno R, Rigamonti L, Bates NA, Krause DA, Crowley E, et al. Multidirectional neck strength characteristics in high school football athletes with and without history of sports-related concussion. Ann Sports Med Res. 2020;7(6):1167.
11. Engelman G, Carry P, Sochanska A, Daoud AK, Wilson J, Provance A. Isometric cervical muscular strength in pediatric athletes with multiple

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

concussions. Clin J Sport Med. 2021;31(1):36–41. http://dx.doi.org/10.1097/JSM.0000000000000681

12. Esopenko C, de Souza N, Conway F, Todaro SM, Brostrand K, Womack J, et al. Bigger necks are not enough: An examination of neck circumference in incoming college athletes. J Prim Prev. 2020;41(5):421–9. http://dx.doi.org/10.1007/s10935-020-00600-5
13. Eckner JT, Oh YK, Joshi MS, Richardson JK, Ashton-Miller JA. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. Am J Sports Med. 2014;42(3):566–76. http://dx.doi.org/10.1177/0363546513517869
14. Jin X, Feng Z, Mika V, Li H, Viano DC, Yang KH. The role of neck muscle activities on the risk of mild traumatic brain injury in American football. J Biomech Eng. 2017;139(10):101002. http://dx.doi.org/10.1115/1.4037399
15. Eckner JT, Lipps DB, Kim H, Richardson JK, Ashton-Miller JA. Can a clinical test of reaction time predict a functional head-protective response? Med Sci Sports Exerc. 2011;43(3):382–7. http://dx.doi.org/10.1249/MSS.0b013e3181f1cc51
16. Nagai T, Schilaty ND, Bates NA, Bies NJ, McPherson AL, Hewett TE. High school female basketball athletes exhibit decreased knee-specific choice visual-motor reaction time. Scand J Med Sci Sports. 2021;31(8):1699–707. http://dx.doi.org/10.1111/sms.13978
17. Vartiainen MV, Holm A, Lukander J, Lukander K, Koskinen S, Bornstein R, et al. A novel approach to sports concussion assessment: Computerized multilimb reaction times and balance control testing. J Clin Exp Neuropsychol. 2016;38(3):293–307. http://dx.doi.org/10.1080/13803395.2015.1107031
18. Silverman IW. Sex differences in simple visual reaction time: A historical meta-analysis. Sex Roles. 2006;54:57–68. http://dx.doi.org/10.1007/s11199-006-8869-6
19. Ingalhalikar M, Smith A, Parker D, Satterthwaite TD, Elliot MA, Ruparel K, et al. Sex differences in the structural connectome of the human brain. Proc Natl Acad Sci U S A. 2014;111(2):823–8. http://dx.doi.org/10.1073/pnas.1316909110
20. Ristanis S, Tsepis E, Giotis D, Stergiou N, Cerulli G, Georgoulis AD. Electromechanical delay of the knee flexor muscles is impaired after harvesting hamstring tendons for anterior cruciate ligament reconstruction. Am J Sports Med. 2009;37(11):2179–86. http://dx.doi.org/10.1177/0363546509340771
21. Hulsdunker T, Gunasekara N, Mierau A. Short- and long-term stroboscopic training effects on visuomotor performance in elite youth sports. Part 1: Reaction and behavior. Med Sci Sports Exerc. 2021;53(5):960–72. http://dx.doi.org/10.1249/MSS.0000000000002541
22. Lempke LB, Howell DR, Eckner JT, Lynall RC. Examination of reaction time deficits following concussion: A systematic review and meta-analysis. Sports Med. 2020;50(7):1341–59. http://dx.doi.org/10.1007/s40279-020-01281-0
23. Churchill NW, Hutchison MG, Graham SJ, Schweizer TA. Brain function associated with reaction time after sport-related concussion. Brain Imaging Behav. 2021;15(3):1508–17. http://dx.doi.org/10.1007/s11682-020-00349-9
24. Valkeinen H, Ylinen J, Malkia E, Alen M, Hakkinen K. Maximal force, force/time and activation/coactivation characteristics of the neck muscles in extension and flexion in healthy men and women at different ages. Eur J Appl Physiol. 2002;88(3):247–54. http://dx.doi.org/10.1007/s00421-002-0709-y
25. Nagai T, Crowley EM, Manuell E, Bates NA, Stuart MJ, Schilaty ND. Sex differences in multidirectional neck muscular strength characteristics in high school soccer athletes. Arch Sports Med. 2020;4(2):224–32. http://dx.doi.org/10.36959/987/257
26. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74. http://dx.doi.org/10.2307/2529310
27. MacDonald J, Wilson J, Young J, Duerson D, Swisher G, Collins CL, et al. Evaluation of a simple test of reaction time for baseline concussion testing in a population of high school athletes. Clin J Sport Med. 2015;25(1):43–8. http://dx.doi.org/10.1097/JSM.0000000000000096
28. Gaudet CE, Konin J, Faust D. Immediate post-concussion and cognitive testing: Ceiling effects, reliability, and implications for interpretation.

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

Arch Clin Neuropsychol. 2021;36(4):561–9. http://dx.doi.org/10.1093/arclin/acaa074
29. Bujang MA, Baharum N. A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: A review. Arch Orofac Sci. 2017;12(1):1–11.
30. Furlan L, Sterr A. The applicability of standard error of measurement and minimal detectable change to motor learning research – A behavioral study. Front Hum Neurosci. 2018;12:95. http://dx.doi.org/10.3389/fnhum.2018.00095
31. Nagai T, Abt JP, Sell TC, Clark NC, Smalley BW, Wirt MD, et al. Neck proprioception, strength, flexibility, and posture in pilots with and without neck pain history. Aviat Space Environ Med. 2014;85(5):529–35. http://dx.doi.org/10.3357/ASEM.3874.2014
32. Krause DA, Hansen KA, Hastreiter MJ, Kuhn TN, Peichel ML, Hollman JH. A comparison of various cervical muscle strength testing methods using a handheld dynamometer. Sports Health. 2019;11(1):59–63. http://dx.doi.org/10.1177/1941738118812767
33. Almosnino S, Pelland L, Stevenson JM. Retest reliability of force-time variables of neck muscles under isometric conditions. J Athl Train. 2010;45(5):453–8. http://dx.doi.org/10.4085/1062-6050-45.5.453
34. Broglio SP, Katz BP, Zhao S, McCrea M, McAllister T, Investigators CC. Test–retest reliability and interpretation of common concussion assessment tools: Findings from the NCAA-DoD CARE Consortium. Sports Med. 2018;48(5):1255–68. http://dx.doi.org/10.1007/s40279-017-0813-0
35. Howell DR, Osternig LR, Chou LS. Detection of acute and long-term effects of concussion: Dual-task gait balance control versus computerized neurocognitive test. Arch Phys Med Rehabil. 2018; 99(7):1318–24. http://dx.doi.org/10.1016/j.apmr.2018.01.025
36. Eckner JT, Kutcher JS, Broglio SP, Richardson JK. Effect of sport-related concussion on clinically measured simple reaction time. Br J Sports Med. 2014;48(2):112–8. http://dx.doi.org/10.1136/bjsports-2012-091579
37. Colvin AC, Mullen J, Lovell MR, West RV, Collins MW, Groh M. The role of concussion history and gender in recovery from soccer-related concussion. Am J Sports Med. 2009;37(9):1699–704. http://dx.doi.org/10.1177/0363546509332497
38. Covassin T, Elbin R, Kontos A, Larson E. Investigating baseline neurocognitive performance between male and female athletes with a history of multiple concussion. J Neurol Neurosurg Psychiatry. 2010;81(6):597–601. http://dx.doi.org/10.1136/jnnp.2009.193797
39. Tsushima WT, Tsushima VG, Murata NM. ImPACT normative data of ethnically diverse adolescent athletes. Clin J Sport Med. 2020;30(1):52–9. http://dx.doi.org/10.1097/JSM.0000000000000567
40. Lavallee AV, Ching RP, Nuckley DJ. Developmental biomechanics of neck musculature. J Biomech. 2013;46(3):527–34. http://dx.doi.org/10.1016/j.jbiomech.2012.09.029
41. Vasavada AN, Danaraj J, Siegmund GP. Head and neck anthropometry, vertebral geometry and neck strength in height-matched men and women. J Biomech. 2008;41(1):114–21. http://dx.doi.org/10.1016/j.jbiomech.2007.07.007
42. Nagai T, Keenan KA, Abt JP, Sell T, Smalley B, Wirt M, et al. A comparison of cervical and trunk musculoskeletal characteristics between female and male army helicopter pilots. Int J Aviat Aeronautics Aerospace. 2016;3(3):1–14. http://dx.doi.org/10.15394/ijaaa.2016.1136
43. Jordan A, Mehlsen J, Bulow PM, Ostergaard K, Danneskiold-Samsoe B. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. Spine (Phila Pa 1976). 1999;24(13):1343–8. http://dx.doi.org/10.1097/00007632-199907010-00012
44. McNair PJ, Depledge J, Brettkelly M, Stanley SN. Verbal encouragement: Effects on maximum effort voluntary muscle action. Br J Sports Med. 1996;30(3):243–5. http://dx.doi.org/10.1136/bjsm.30.3.243
45. Campenella B, Mattacola CG, Kimura IF. Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. Isokinet Exerc Sci. 2000;8:1–6. http://dx.doi.org/10.3233/IES-2000-0033
46. Andersen LL, Aagaard P. Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. Eur J Appl Physiol. 2006;96(1):46–52. http://dx.doi.org/10.1007/s00421-005-0070-z
47. Kroshus E, Baugh CM, Stein CJ, Austin SB, Calzo JP. Concussion reporting, sex, and

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022

conformity to traditional gender norms in young adults. J Adolesc. 2017;54:110–9. http://dx.doi.org/10.1016/j.adolescence.2016.11.002
48. Burman E, Lysholm J, Shahim P, Malm C, Tegner Y. Concussed athletes are more prone to injury both before and after their index concussion: A data base analysis of 699 concussed contact sports athletes. BMJ Open Sport Exerc Med. 2016;2(1):e000092. http://dx.doi.org/10.1136/bmjsem-2015-000092
49. Clark JF, Betz BE, Borders LT, Kuehn-Himmler A, Hasselfeld KA, Divine JG. Vision training and reaction training for improving performance and reducing injury risk in athletes. J Sports Perf Vis. 2020;1(1):e8–16. http://dx.doi.org/10.22374/jspv.v2i1.4
50. Clark JF, Graman P, Ellis JK, Mangine RE, Rauch JT, Bixenmann B, et al. An exploratory study of the potential effects of vision training on concussion incidence in football. Optom Vis Perf. 2015;3(2):116–25.

DOI: https://doi.org/10.22374/jspv.v4i1.11
J Sports Perf Vis 4(1):e1–e13; 7 April 2022