J Am Acad Audiol 28:36–45 (2017)

Examining Effects of Physical Exertion on the Dynamic Visual Acuity Test in Collegiate Athletes

DOI: 10.3766/jaaa.15110

Jessie N. Patterson*
Anna M. Murphy*
Julie A. Honaker*

Abstract

Background: Acute symptoms of dizziness and/or imbalance commonly experienced in athletes postconcussion are speculated to arise from dysfunction at multiple levels (i.e., inner ear or central vestibular system) to appropriately integrate afferent sensory information. Disruption along any pathway of the balance system can result in symptoms of dizziness, decreased postural control function (vestibulospinal reflex), and reduced vestibulo-ocular reflex function. This may also lead to decreased gaze stability with movements of the head and may account for symptoms of blurred vision or diplopia reported in almost half of athletes sustaining a concussion. Current concussion position statements include measures of postural control to examine changes to the balance system postconcussion. The Balance Error Scoring System (BESS) is a commonly used low-cost postural control measure for concussion assessment. Although this is a widely used measure for documenting balance function on both immediate (sideline) and recovery monitoring, the BESS has been shown to be affected by physical exertion. Therefore, the BESS may not be the most efficient means of examining functional changes to the balance system immediately after head injury. Dynamic Visual Acuity Test (DVAT) has been found to effectively evaluate and monitor changes to the gaze stability system postinjury. Thus, DVAT may be an additional measure in the concussion assessment battery, as well as an alternative for more immediate sideline assessment to help make objective return-to-play decisions.

Purpose: The aim of the study was to determine the effects of physical exertion on a clinical vestibular assessment, the DVAT, in collegiate athletes, as a first step in defining the role of this measure in the concussion assessment battery.

Research Design: Cross-sectional, repeated-measures design.

Study Sample: Twenty-eight healthy collegiate athletes (20 males, 8 females; age = 20.25 ± 1.46 yr, range = 18–25 yr) volunteered to participate in the study.

Data Collection and Analysis: Participants were randomly assigned to complete a 20-min protocol of physical exertion or rest. DVAT was completed pre-exertion or rest (pre-DVAT), immediately following the 20-min protocol (post-DVAT I), and again 10 min after the completion of the 20-min protocol (post-DVAT II). Ratings of perceived exertion (RPE) and heart rate (HR) were monitored throughout testing. Repeated-measures analysis of the variance were used to examine the effects of exertion on DVAT. Additionally, intraclass correlation coefficients were used to examine test reliability.

Results: No significant main effect was observed for right and left DVAT logarithm of the minimal angle of resolution loss between groups or across time points ($p > 0.05$). A significant main effect was observed for RPE and HR for groups and time points ($p < 0.001$), indicating adequate physical exertion and rest. Fair to good reliability (intraclass correlation coefficient values between 0.4 and 0.74) was observed for both rightward and leftward movements of the head across the three time points.

Conclusions: Findings from this study suggest that DVAT is not affected by physical exertion and may provide a more immediate assessment of the balance system that may be of use for the sideline concussion assessment. Future studies will be performed to examine additional factors (e.g., background noise, complex visual backgrounds) that may affect DVAT performance in the sideline environment.

*Department of Special Education and Communication Disorders, University of Nebraska-Lincoln, Lincoln, NE

Corresponding author: Julie A. Honaker, Ph.D., University of Nebraska-Lincoln, Lincoln, NE 68588-0156; E-mail: jhonaker2.unl@gmail.com

Key Words: athletes, concussion, dynamic visual acuity, DVAT, physical exertion, sport-related head injury, vestibular function, vestibulo-ocular reflex, visual–vestibular, VOR

Abbreviations: BESS = balance error scoring system; DVAT = Dynamic Visual Acuity Test; HR = heart rate; ICC = intraclass correlation coefficients; logMAR = logarithm of the minimal angle of resolution; NCCA = National Collegiate Athletic Association; PTT = Perception Time Test; RPE = ratings of perceived exertion; SD = standard deviation; SVA = static visual acuity; VOR = vestibulo-ocular reflex

INTRODUCTION

Our balance system relies on adequate integration of multisensory inputs (vision, vestibular, and somatosensory) and motor outputs via the central nervous system to communicate the position and orientation of the body in comparison to the external environment. Disruption to this intricate sensorimotor system results in symptoms of dizziness and unsteadiness and clinical signs of impaired gaze stability and postural control. In addition to headaches, dizziness and/or imbalance are some of the most common symptoms for athletes sustaining a concussion (Binder, 1997; Ingebrigtsen et al, 1998; van der Naalt, 2001; Alsalaheenet al, 2010; 2013), and the severity of these symptoms can range from off-balance or light-headedness to true vertigo (Alsalaheen et al, 2010). The effects of a concussion include both peripheral vestibular system involvement (i.e., semicircular canals, otolith organs, vestibular nerve) and central vestibular system involvement (Fife and Kalra, 2015; Valvoich McLeod and Hale, 2015). Since the pathways involved in stable gaze and postural control can be so complex, it is difficult to localize one specific site of lesion that may be causing these postconcussion symptoms (Ellis et al, 2015). Rather, dysfunction may occur on multiple levels (Ellis et al, 2015), or be dysfunctional at the level of the central nervous system in order to appropriately integrate the afferent sensory information (Murray et al, 2014). Disruption along any pathway of the balance system can result in symptoms of dizziness, as well as postural control dysfunction, and reduced vestibulo-ocular reflex (VOR) function with movement of the head (i.e., visual blurring with movement of the head) in the acute phase (Mucha et al, 2014; Ellis et al, 2015; Honaker et al, 2015). This may also lead to a decreased gaze stability with movements of the head and may account for symptoms of blurred vision or diplopia reported in 49% of athletes sustaining a concussion (Lovell, 2009; Aligene and Lin, 2013).

Stable gaze is imperative to an athlete's performance and safety in dynamic environments (e.g., running, while trying to catch a ball) (Zhou and Brodsky, 2015). The Dynamic Visual Acuity Test (DVAT) is an objective clinical measure that both evaluates and monitors the visual-vestibular system (i.e., VOR). Specifically, DVAT quantifies visual acuity during both active and passive movements of the head (dynamic) and compares an individual's performance to the visual acuity obtained with the head in a still position (static). Previous studies have found abnormal DVAT performance in both youth and adults with posthead injuries (concussion and blast injury) (Gottshall et al, 2003; 2007; Gottshall and Hoffer, 2010; Valvoich McLeod and Hale, 2015; Zhou and Brodsky, 2015). Recent work has revealed that a large proportion of athletes who have sustained a concussion exhibit abnormal DVAT (i.e., decreased visual acuity with movements of the head) without concurrent abnormal caloric and rotary chair responses; thus, supporting the theory of a central disruption rather than peripheral vestibular hypofunction (Zhou and Brodsky, 2015). Therefore, there are recommendations emerging to include DVAT in head injury management protocol to evaluate and monitor changes in DVAT performance (Gottshall et al, 2003; 2007; Gottshall and Hoffer, 2010; Kaufman et al, 2014).

Currently, the function of the balance system in athletes is most commonly assessed on the sidelines with a low-cost postural control measure known as the Balance Error Scoring System (BESS). The BESS assesses an individual's ability to maintain an upright stance under six challenging conditions and is an objective measure of the postural control system (Guskiewicz et al, 2001). One limitation of the BESS is that it lacks direct assessment of vestibular function. Additionally, the BESS is affected by physical exertion and therefore, should not be assessed until ~15–20 min after physical exertion (Susco et al, 2004; Wilkins et al, 2004; Fox et al, 2008). A long wait time is not ideal in the athletic environment, as healthcare professionals are expected to assess a potential head injury immediately (i.e., directly after the performance of a physical task) to make decisions regarding a safe return to play. Therefore, there is urgency to find objective measures (i.e., not based on the athlete's report of symptoms) that are not affected by physical exertion and also to assess the impairments of the balance system.

As stated previously, DVAT has been found to be an effective clinical tool in evaluation and monitoring changes to the visual–vestibular system postinjury; thus, DVAT may be an appropriate alternative for sideline assessment and may help professionals make more immediate and objective return-to-play decisions. Therefore, the purpose of this study was to investigate the effects of physical exertion on DVAT and to determine the reliability of DVAT in collegiate athletes as a first step in defining the role of DVAT in the sideline concussion assessment battery.

METHODS

Participants

Participants were recruited from the National Collegiate Athletic Association (NCAA) Division I and club sport athletic teams at the University of Nebraska–Lincoln. Participation in the study took place during the athletes' off-season. It was determined that a sample size of 14 participants in each group (using a moderate, 0.25, effect size) was needed for adequate statistical power (80%, $p < 0.05$). Thus, our sample consisted of 28 healthy participants, 22 NCAA Division I athletes and 6 club athletes (20 male, 8 female: age = 20.25 ± 1.46 yr, range = 18–25 yr). Participants included members from the following NCAA teams: wrestling ($n = 6$), football ($n = 3$), baseball ($n = 3$), track and field ($n = 5$), gymnastics ($n = 2$), golf ($n = 2$), and bowling ($n = 1$). Participants included members from the following Club sport teams: rugby ($n = 1$), lacrosse ($n = 1$), ultimate Frisbee ($n = 1$), running ($n = 1$), swimming and diving ($n = 1$), and soccer ($n = 1$). Participants were excluded from the study if they met any of the following criteria: (a) any condition that caused a reduction in the individual's ability to perform physical exertion tasks (i.e., an orthopedic condition or cardiovascular issues), (b) limited cervical range of motion (i.e., limited horizontal movements of the head to the right or left), (c) history of a diagnosed concussion within 6 mo of the assessment, (d) a known inner ear disorder, and (e) alcohol consumption 24 hr prior to testing; based on the above criteria, no participants were excluded. Participants were randomly assigned to either the physical exertion or rest group. The University of Nebraska–Lincoln institutional review board approved the study and informed consent. All participants read and signed the consent form prior to participation.

Instrumentation

DVAT

For the DVAT protocol, participants sat in a sturdy chair 10′ from a computer screen placed in front of a solid white wall. DVAT was completed with the *in*Vision package from VSR Sport (NeuroCom International, a division of Natus, Pleasonton, CA) equipment (portable equipment). All participants were tested for his or her best-corrected vision (i.e., wearing contacts or glasses if needed). As part of the standard protocol for *in*Vision, and to document changes in visual acuity with movements of the head, all participants first completed Static Visual Acuity (SVA) and Perception Time Test (PTT). SVA is a measure of an individual's visual acuity, obtained from both eyes and with the head still. To measure this, an optotype (the letter E) appeared on the computer screen in randomized inversions and participants were instructed to indicate the direction of the legs of the "E" (i.e., up, down, left, or right). Based on a standard psychophysical adaptive process, the SVA score was obtained at the threshold (i.e., the smallest accurately perceived orientation of the visual target at 60%) (NeuroCom International, Inc., 2011). SVA scores were then converted from Snellen fractions to logarithm of the minimal angle of resolution (logMAR) units (NeuroCom International, Inc., 2011) (Table 1). Larger logMAR (positive values) indicated decreased visual acuity and negative logMAR indicated visual acuity better than 20/20 (NeuroCom International, Inc., 2011). Next, PTT was measured. The athlete's head remained still and he/she was then instructed to again identify the orientation of the optotype E that flashed on the screen; however, the optotype was presented at a fixed size of 0.2 logMAR greater than the obtained SVA value. Minimum time, in milliseconds, was used to accurately perceive the optotype (60%) and was calculated as the PTT score. Participants with PTT scores >60 msec were excluded; please note that we used a more conservative cut-off for PTT, whereas previous studies used >70 msec (Mohammed et al, 2011) and >80 msec (Kaufman et al, 2014). Increased PTT scores lead to an increased optotype presentation during DVAT and could allow for alternative oculomotor systems (e.g., saccades, gaze holding) to fixate the eyes on the optotype rather than the VOR (Honaker and Shepard, 2011; Mohammed et al, 2011). No participants were excluded based on this criterion.

Table 1. Snellen Fraction to logMAR Conversion from the NeuroCom Clinical Integration Laboratory Manual (NeuroCom International, Inc., 2013)

Snellen Fraction	logMAR Score
20/200	+1.00
20/160	+0.90
20/125	+0.80
20/100	+0.70
20/80	+0.60
20/65	+0.50
20/50	+0.40
20/30	+0.20
20/25	+0.10
20/20	+0.00
20/13	−0.10
20/10	−0.30

DVAT was completed with passive movements of the head (i.e., the examiner moved the participant's head) in the yaw plane with 20° excursions to the right and left at a target velocity of at least 120°/sec. Participants wore an accelerometer (InertiaCube2+, Sourceless 3DOF Tracker, Billercia, MA) on their heads to monitor head amplitude and velocity. The optotype (the letter E) appeared on the screen in randomized inversions once the targeted head velocity was achieved to avoid the participant utilizing central oculomotor mechanisms (e.g., smooth pursuit, gaze holding) to fixate on the optotype. Again, the athlete was asked to indicate the direction of the legs of the "E" (i.e., right, left, up, or down). Similar to SVA, visual acuity scores were calculated based on the number of correct responses of the participant; when the participant accurately identified the direction of the optotype at 60%, the optotype size decreased, until the participant was unable to accurately identify the optotype direction (NeuroCom International, Inc., 2011). DVAT scores were also converted from Snellen fraction to logMAR and compared to SVA values to obtain a DVAT logMAR loss value for both rightward and leftward movements of the head (i.e., a difference in the size of the optotype when the head was in motion compared to when the head was still). The examiner was provided visual feedback on the computer screen to achieve optimal velocity and excursion throughout the testing, and adequate practice was achieved prior to performing the research measure.

Borg 15-Point Scale and Heart Rate

Ratings of perceived exertion (RPE) and heart rate (HR) were monitored throughout testing to ensure adequate exertion and rest. The Borg 15-Point Scale (Borg, 1982) is a widely accepted scale to monitor RPE, with 6 points indicating no exertion (i.e., rest) and 20 points indicating maximal exertion levels. Further, this scale was used in previous work to examine the effects of exertion on postural control (BESS) (Susco et al, 2004; Wilkins et al, 2004). Based on the work of Robertson et al (2000) and Moyna et al (2001), as well as Susco et al (2004), a score of 15 ("hard or heavy") on the Borg 15-Point Scale was considered adequate for exertion levels and has been correlated with 75–90% maximum oxygen consumption (Moyna et al, 2001; Robertson et al, 2000). The Nonin GO_2 (Plymouth, MN) Achieve was used to measure HR in beats per minute.

Procedures

All participants were asked to first complete a preliminary SVA and PTT one time prior to administration of the three DVAT tests. The rest group first performed DVAT, prior to the beginning of a 20-min rest period (pretest), whereas the physical exertion group completed DVAT first, prior to beginning a 20-min exertion protocol (pretest). All participants in the physical exertion group completed seven stations of physical activity in the same consecutive order (Station 1–7). All stations were set-up to allow the participants to immediately move from one station to the next (i.e., minimal to no rest time between the different stations). The physical exertion protocol was based on the work of Susco et al (2004) and Wilkins et al (2004) to examine the effects of fatigue on postural control measures. The components of the physical exertion protocol are described in more detail in Table 2. We offered verbal cues throughout the physical exertion tasks to ensure that participants were exhibiting maximal effort. After completion of the 20-min physical exertion protocol or 20-min rest protocol, participants in both groups completed DVAT again (posttest I), and for a third time 10 min after completing the 20-min rest or physical exertion protocol (posttest II). See Figure 1 for a more detailed outline of the protocol for both the physical exertion and rest groups. The reason for the third time point (i.e., 10 min after completion of the rest or physical exertion task) was to either accept our research hypothesis (no change in DVAT performance immediately following physical exertion) or reject our research hypothesis (a DVAT change immediately following physical exertion) thus suggesting the need to wait a period of time prior to testing; a waiting period of 10 min would be less than the waiting period required for administering the BESS.

Table 2. Twenty-Minute Physical Exertion Protocol

Station	Activity	Duration (min)
1	Moderate jog at the athlete's self-selected pace	5
2	Sprints	3
3	Push-ups	2
4	Sit-ups	2
5	12″ step-ups	3
6	Sprints	3
7	Run (maintain the fastest pace they could for the entire time)	2

Note: Based on the work of Susco et al (2004) and Wilkins et al (2004).

RPE and HR were recorded in both groups at four intervals: (a) prior to beginning physical exertion or rest, (b) 10 min into the physical exertion or rest protocol, (c) immediately following the 20-min physical exertion or rest protocol (immediately prior to posttest I), and (d) 10 min after the completion of the 20-min physical exertion or rest protocol (immediately prior to posttest II). Please refer to Figure 1 for a more detailed outline of HR monitoring and RPE recordings during the assessment protocol for both the control and physical exertion participants. The entire test battery from start to finish took ~35–40 min of the participant's time, including the consent process; the participants were tested in a single session, which took place in an athletic performance laboratory.

Statistical Analysis

Descriptive statistics (mean, standard deviation [SD], and range) were calculated for SVA, PTT, right and left DVAT logMAR loss, Borg RPE, and HR. To examine differences in right and left DVAT logMAR loss

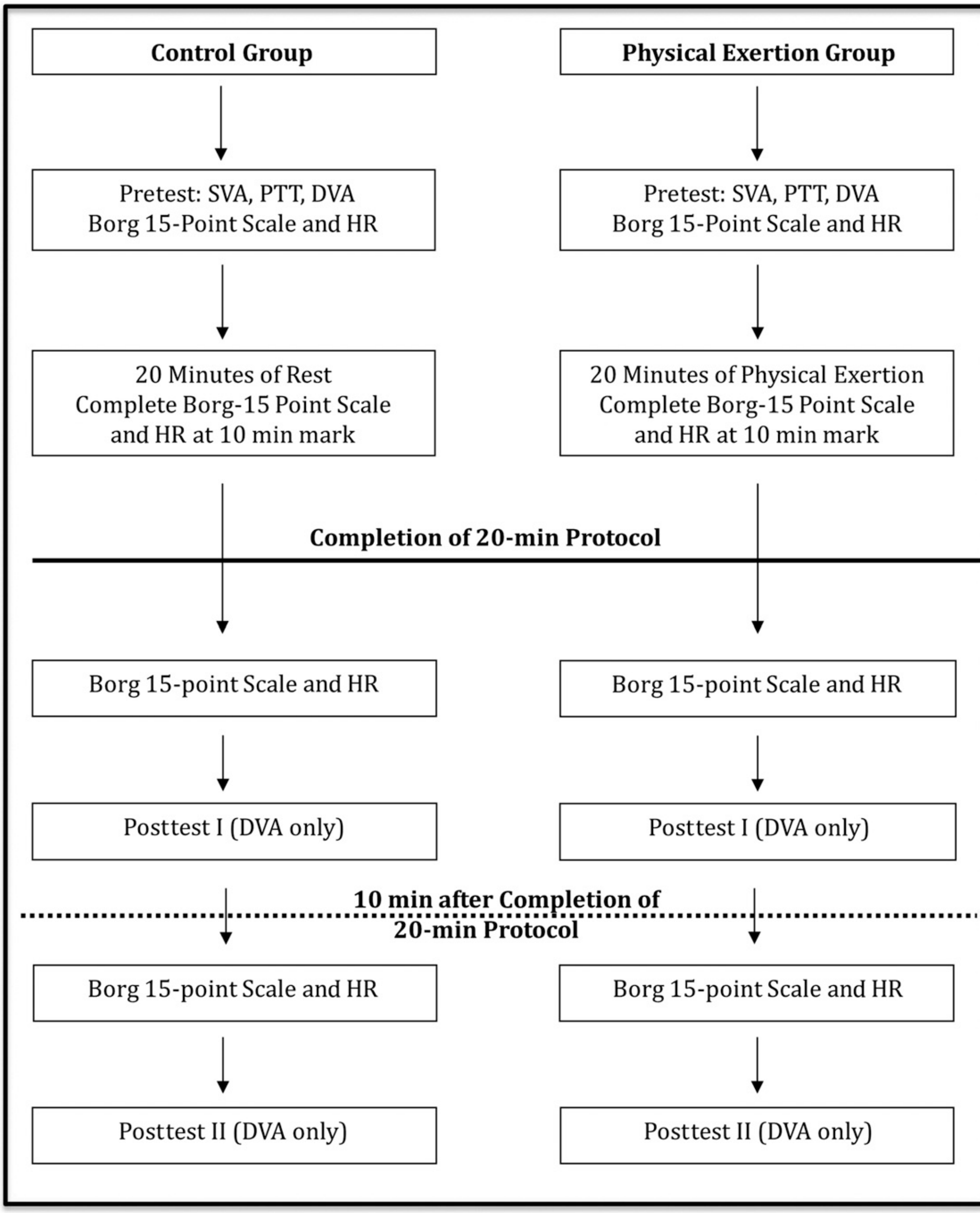

Figure 1. Outline of the protocol for both the physical exertion and the rest groups. This test protocol is based on the work of Susco et al (2004), Wilkins et al (2004), and Fox et al (2008) examining the effects of fatigue on the BESS.

values, Borg RPE and HR at three times points (pre, post-I, and post-II) in the two groups (i.e., physical exertion and control), we used mixed between-within subjects analysis of variance. Intraclass correlation coefficients (ICC; two-way mixed effects model and absolute agreement) with 95% confidence intervals were calculated to examine the reliability of DVAT across the three time points. Based on the work of Fleiss (1986), ICC values of <0.4 were considered poor, values between 0.4–0.74 were considered to be fair to good, and values >0.75 were considered to be excellent. All data were computed and analyzed using SPSS statistical software (version 21; SPSS Inc., Chicago, IL).

RESULTS

All participants were able to complete DVAT testing at each time point (Table 3). Average SVA was −0.24 (SD = 0.09, range = −0.30 to −0.15) and PPT was 20.4 (SD = 1.89, range = 20–30) for all participants. No significant main effect was observed between right or left DVAT logMAR loss across the three times

Table 3. Descriptive Statistics (Mean ± SD and Range) for Right and Left DVA logMAR Loss for the Physical Exertion and Rest Groups at Each Time Point

	Pre DVA Loss		Post I DVA Loss		Post II DVA Loss	
Group	Right	Left	Right	Left	Right	Left
Physical exertion	0.08 ± 0.09	0.10 ± 0.08	0.06 ± 0.11	0.13 ± 0.14	0.07 ± 0.08	0.09 ± 0.09
	−0.10 to 0.28	0.00 to 0.20	−0.08 to 0.30	−0.07 to 0.45	0.00 to 0.26	0.00 to 0.32
Rest	0.10 ± 0.08	0.09 ± 0.09	0.12 ± 0.11	0.11 ± 0.12	0.09 ± 0.11	0.10 ± 0.13
	−0.01 to 0.22	−0.05 to 0.30	−0.06 to 0.30	−0.06 to 0.30	−0.06 to 0.27	−0.10 to 0.27

points (pre, post-I, and post-II), Wilks' lambda = 0.958, $F_{(4,23)} = 0.255$, $p = 0.904$. In addition, no significant main effect was observed between the physical exertion and the rest group for right and left DVAT logMAR loss, Wilks' lambda = 0.884, $F_{(2, 25)} = 1.64$, $p = 0.215$ (see Figure 2). Also, the paired-samples t test was not significant, suggesting no learning effect with repeated testing.

As anticipated, a significant effect was observed for Borg and time point, $F_{(2,50)} = 170.52$, $p < 0.001$, and a significant interaction between time and group was observed for Borg, $F_{(2,50)} = 203.28$, $p < 0.001$ (Figure 3). Pairwise comparisons revealed significant differences in Borg rating between each time point ($p < 0.05$). Average Borg RPE for the physical exertion and rest groups at Post-1 time point was 15.79 and 6.1, respectively. A significant difference was also observed for HR and time point, $F_{(2,42)} = 157.09$, $p < 0.001$, and a significant interaction was observed for time and group, $F_{(2,42)} = 203.29$, $p < 0.001$ (Figure 4). Pairwise comparisons revealed a significant difference in HR between each time point ($p < 0.001$).

The DVAT response reliability was examined across the three time points for right, left and average (right and left) DVAT logMAR losses. Fair to good reliability (ICC values between 0.4 and 0.74) was observed for all three DVAT responses (Table 4).

DISCUSSION

Concussions are a growing concern for athletes, parents, and health-care professionals. Specifically,

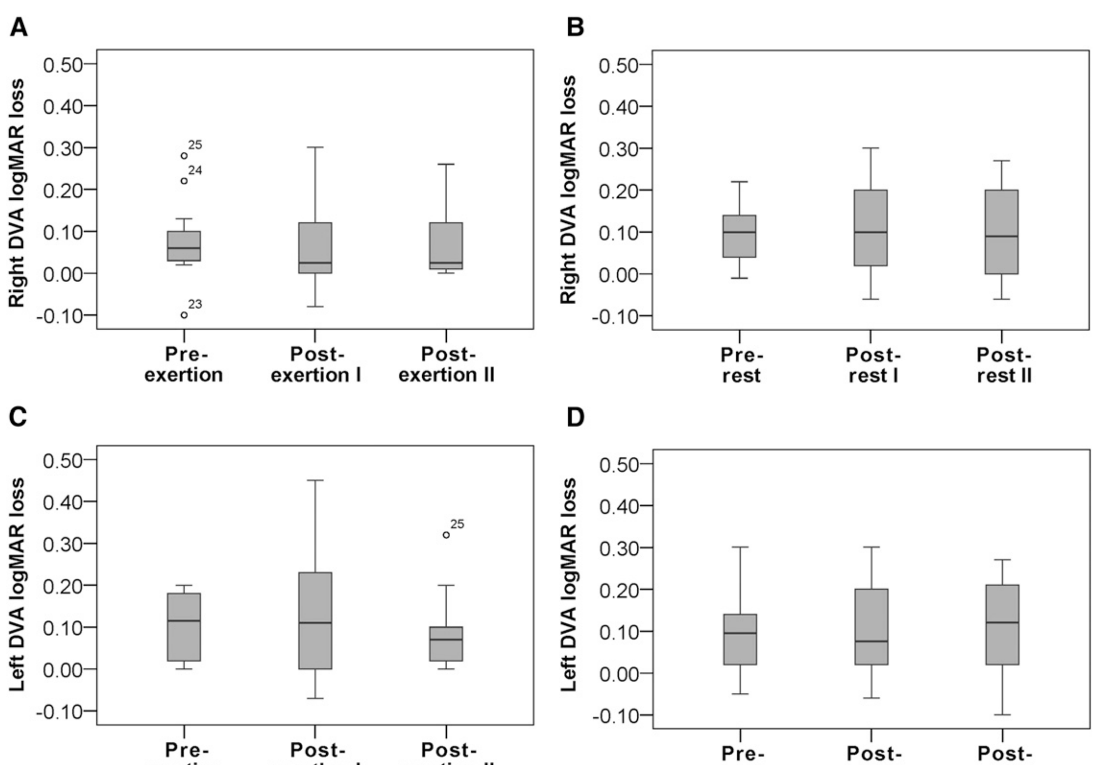

Figure 2. Median DVAT logMAR loss for rightward movement for the (A) physical exertion and (B) rest groups, and leftward movement for the (C) physical exertion and (D) rest groups, across the three time points (pre-exertion I, post-exertion I, and post-exertion II). The numbers indicate participants that are outliers.

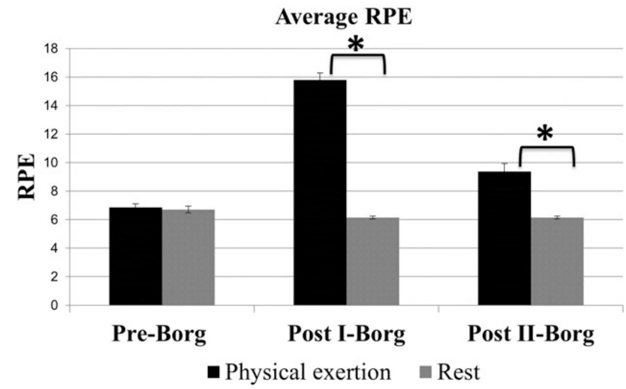

Figure 3. RPE for both groups (physical exertion and rest), across the three time points (pre-Borg, post I-Borg, and post II-Borg). A score of 15 ("hard or heave") on the Borg 15-Point Scale was deemed adequate exertion and has been correlated with 75–90% maximum oxygen consumption (Robertson et al, 2000; Moyna et al, 2001; Susco et al, 2004). $*p < 0.05$.

determining objective and accurate measures to help determine safe return to play appears to be a necessary task for health-care professionals. As stated previously, dizziness and/or imbalance, and blurred vision or diplopia are common symptoms for athletes and military personnel sustaining a head injury (Binder, 1997; Ingebrigtsen et al, 1998; van der Naalt, 2001; Gottshall et al, 2003; Gottshall and Hoffer, 2010). The exact mechanisms causing dizziness and vertigo, as a result of a concussion, are still under investigation. Concussions have been found to affect both the peripheral vestibular mechanisms, and the central vestibular pathways (Linthicum and Rand, 1931; Barber, 1969; Kay et al, 1971; Gannon et al, 1978) and this disruption can result in difficulty with standing balance or gaze stability (Mucha et al, 2014; Ellis et al, 2015; Honaker et al, 2015). Specifically, we can see gaze stability symptoms brought out during movements of the head, and due to this, emerging literature recommends the use of DVAT posthead injury, including concussion (Gottshall et al, 2003; 2007; Gottshall and Hoffer, 2010; Kaufman et al, 2014). Based on our findings, DVAT may be warranted as a more immediate postconcussion assessment.

To our knowledge, this is the first study examining the effects of physical exertion on the DVAT test. Our results revealed that DVAT, a clinical visual–vestibular measure, was not affected by physical exertion. This is contrary to previous results found using other balance measures (i.e., postural control measures, Susco et al, 2004; Wilkins et al, 2004; Fox et al, 2008). There was no change in DVAT logMAR loss for both rightward and leftward movements of the head across the three time points for both groups. Furthermore, our results, as well as results from Kaufman et al (2014) and Ward et al (2010) revealed fair to good test–retest reliability for DVAT response (DVAT logMAR loss; Table 4) for serial monitoring of changes in function over time. Therefore, DVAT may be an alternative option for more immediate postconcussion balance assessment on the sideline, and a complement to existing concussion assessment measures (i.e., postural control).

Recently, Mucha et al (2014) developed a vestibular/ocular motor screening (VOMS) to evaluate symptoms of dizziness postconcussion. This screening measure (5–10 min in duration) examines athlete reported symptoms during seven subtests examining ocular-motor and VOR function. Results from this study suggest that using this screener had high sensitivity and specificity for identifying concussions; however, one limitation of this screening protocol is that it relies on the athletes to report symptoms (Mucha et al, 2014). It is well documented that athletes underreport symptoms postconcussion to avoid sitting out of play (McCrea et al, 2004; Williamson and Goodman, 2006). One advantage of DVAT is that it provides an objective measure of visual acuity during movements of the head that can be compared back to the athlete's baseline performance and do not rely on symptom report from the athlete.

Clinical Significance

Accurate, objective, and immediate sideline concussion assessments regarding safe return to play have proven to be a challenging task for the health-care professionals involved (i.e., the team physician or athletic trainer) (Putukian et al, 2013). Current concussion position statements and evidence-based practice guidelines recommend balance and gait measures for concussion identification and recovery monitoring (Notebaert and Guskiewicz, 2005; Giza et al, 2013; McCrory et al, 2013); however, the specific recommendations of balance measures often only include postural control assessment (Guskiewicz et al, 2004; Giza et al, 2013; Harmon et al, 2013). These measures assess an individual's ability to maintain upright stance, but do not provide insight into

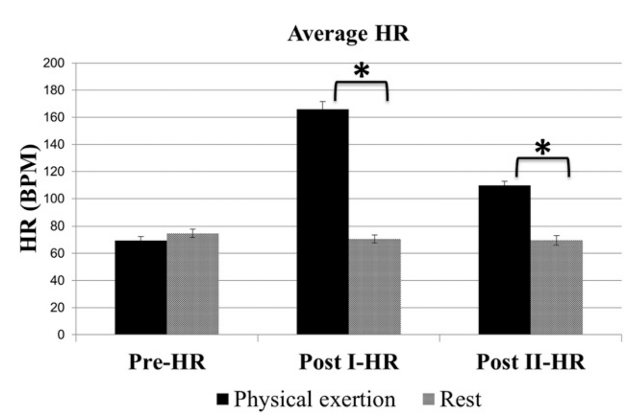

Figure 4. Average HR for both groups (physical exertion and rest), across the three time points (pre-HR, post I-HR, and post II-HR). $*p < 0.05$. BPM = beats per minute.

Table 4. ICC with 95% Confidence Interval (CI) for DVA logMAR Compared to Previous Studies

	Time between Test–Retest	Population	Average DVA logMAR ICC (95% CI)	Right DVA logMAR ICC (95% CI)	Left DVA logMAR ICC (95% CI)
Current study (Patterson et al)	Same day	Collegiate athletes	0.708* (0.452–0.855)	0.530* (0.108–0.769)	0.481* (0.022–0.744)
Kaufman et al (2014)	Mean time between tests = 6.1 days ± 3.6	Collegiate athletes	0.786** (0.551–0.898)	—	—
Ward et al (2010)	Same day	Young adults (mean age = 25.2 ± 3.2 yr)	0.51* (0.10–0.77)	—	—

Note: Based on the work of Fleiss (1986): ICC values <0.4 were considered poor, *values between 0.4 and 0.74 were considered to be fair to good, and **values ≥0.75 were considered to be excellent.

potential deficits to an athlete's visual–vestibular system. As stated previously, symptoms of dizziness, blurred vision, and diplopia are common following a head injury (Lovell, 2009; Aligene and Lin, 2013), and DVAT testing is warranted to objectively assess the gaze stability system in order to ensure clear vision during head movements and to determine safe return to play.

Limitations

While our results suggest that there is no effect of physical exertion on DVAT, this study was performed in a controlled environment, and it is not realistic to sideline concussion assessment. All testing was completed in a quiet environment and the computer screen was placed on a plain, white wall to avoid any visual distractions. Therefore, it is unknown how background noise and visually complex environments will impact DVAT performance. BESS performance has been shown to decrease (i.e., increase in the number of errors) in the sideline environment (Onate et al, 2007; Rahn et al, 2015). To our knowledge, the effects of background noise and visually complex scenery on DVAT have not been investigated and future studies will need to explore this.

Another limitation of this study was the lack of repeated SVA and PTT at the repeated time points. Since we did not test SVA and PTT immediately following physical exertion, we cannot say whether there was an effect of physical exertion on either of these test measures that may have impacted the DVAT results. However, since there does not appear to be a significant difference in DVAT scores, it is suggested that SVA and PTT were stable as well.

Furthermore, there is the possibility of learning effects from the pretest to the posttests. Clinically, we aimed to get the individual's best performance on this novel task; therefore, abnormal findings were repeated to ensure accurate results. Furthermore, paired-sample *t* tests between time points were not significantly different from one another and support that performance did not significantly improve in the later trials due to practice or learning effects. Contrary to our findings, Kaufman et al (2014) found a significant difference in DVAT performance from the initial test to the second test (mean time between test = 6.1 days, SD = ±3.6) that may suggest a learning effect. The authors suggest that by performing multiple initial tests (i.e., repeating to get the best performance), learning effects may decrease and the clinical usefulness may increase (Kaufman et al, 2014). Finally, future studies need to examine the test–retest reliability of DVAT that is more realistic to when DVAT would actually be administered postconcussion (i.e., months to years following baseline testing). Determining the test–retest reliability and reliable change indices using a more realistic time interval will help determine the clinical utility of DVAT in the concussion assessment battery.

CONCLUSIONS

There is a need for health-care professionals to make quick decisions on the sideline regarding safe return to play. For a safe return to play, it is imperative that the athletes' have functioning visual–vestibular systems to maintain clear visual imaging of the world while in these dynamic environments. Therefore, incorporating DVAT postconcussion in addition to postural control measures may ensure safer return to play. Our preliminary findings suggest that DVAT was not affected by physical exertion and this test may provide a more immediate measure postconcussion. The authors recognize that inclusion of DVAT into the concussion protocol will not replace the BESS but could complement the current concussion standards for balance concussion assessment. Future study will need to examine other factors that may influence sideline performance on DVAT, as well as determine the clinical utility of DVAT in the concussion assessment battery.

REFERENCES

Aligene K, Lin E. (2013) Vestibular and balance treatment of the concussed athlete. *NeuroRehabilitation* 32(3):543–553.

Alsalaheen BA, Mucha A, Morris LO, Whitney SL, Furman JM, Camiolo-Reddy CE, Collins MW, Lovell MR, Sparto PJ. (2010)

Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther* 34(2):87–93.

Alsalaheen BA, Whitney SL, Mucha A, Morris LO, Furman JM, Sparto PJ. (2013) Exercise prescription patterns in patients treated with vestibular rehabilitation after concussion. *Physiother Res Int* 18(2):100–108.

Barber HO. (1969) Head injury audiological and vestibular findings. *Ann Otol Rhinol Laryngol* 78(2):239–252.

Binder LM. (1997) A review of mild head trauma. Part II: Clinical implications. *J Clin Exp Neuropsychol* 19(3):432–457.

Borg GA. (1982) Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 14(5):377–381.

Ellis MJ, Leddy JJ, Willer B. (2015) Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: an evidence-based classification system with directions for treatment. *Brain Inj* 29(2):238–248.

Fife TD, Kalra D. (2015) Persistent vertigo and dizziness after mild traumatic brain injury. *Ann N Y Acad Sci* 1343:97–105.

Fleiss JL. (1986) *Design and Analysis of Clinical Experiments*. New York, NY: John Wiley & Sons.

Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. (2008) Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train* 43(5):456–463.

Gannon RP, Willson GN, Roberts ME, Pearse HJ. (1978) Auditory and vestibular damage in head injuries at work. *Arch Otolaryngol* 104(7):404–408.

Giza CC, Kutcher JS, Ashwal S, Barth J, Getchius TS, Gioia GA, Gronseth GS, Guskiewicz K, Mandel S, Manley G, McKeag DB, Thurman DJ, Zafonte R. (2013) Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology* 80(24):2250–2257.

Gottshall K, Drake A, Gray N, McDonald E, Hoffer ME. (2003) Objective vestibular tests as outcome measures in head injury patients. *Laryngoscope* 113(10):1746–1750.

Gottshall KR, Gray NL, Drake AI, Tejidor R, Hoffer ME, McDonald EC. (2007) To investigate the influence of acute vestibular impairment following mild traumatic brain injury on subsequent ability to remain on activity duty 12 months later. *Mil Med* 172(8):852–857.

Gottshall KR, Hoffer ME. (2010) Tracking recovery of vestibular function in individuals with blast-induced head trauma using vestibular-visual-cognitive interaction tests. *J Neurol Phys Ther* 34(2):94–97.

Guskiewicz KM, Bruce SL, Cantu RC, Ferrara MS, Kelly JP, McCrea M, Putukian M, Valovich McLeod TC. (2004) National athletic trainers' association position statement: Management of sport-related concussion. *J Athl Train* 39(3):280–297.

Guskiewicz KM, Ross SE, Marshall SW. (2001) Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athl Train* 36(3):263–273.

Harmon KG, Drezner JA, Gammons M, Guskiewicz KM, Halstead M, Herring SA, Kutcher JS, Pana A, Putukian M, Roberts WO. (2013) American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med* 47(1):15–26.

Honaker JA, Criter RE, Patterson JN, Jones SM. (2015) Gaze stabilization test asymmetry score as an indicator of previous concussion in a cohort of collegiate football players. *Clin J Sport Med* 25(4):361–366.

Honaker JA, Shepard NT. (2011) Use of the Dynamic Visual Acuity Test as a screener for community-dwelling older adults who fall. *J Vestib Res* 21(5):267–276.

Ingebrigtsen T, Waterloo K, Marup-Jensen S, Attner E, Romner B. (1998) Quantification of post-concussion symptoms 3 months after minor head injury in 100 consecutive patients. *J Neurol* 245(9):609–612.

Kaufman DR, Puckett MJ, Smith MJ, Wilson KS, Cheema R, Landers MR. (2014) Test-retest reliability and responsiveness of gaze stability and dynamic visual acuity in high school and college football players. *Phys Ther Sport* 15(3):181–188.

Kay DW, Kerr TA, Lassman LP. (1971) Brain trauma and the post-concussional syndrome. *Lancet* 298(7733):1052–1055.

Linthicum FH, Rand CW. (1931) Neuro-otological observations in concussion of the brain. *Arch Otolaryngol* 13:785–821.

Lovell M. (2009) The management of sports-related concussion: current status and future trends. *Clin Sports Med* 28(1):95–111.

McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. (2004) Unreported concussion in high school football players: implications for prevention. *Clin J Sport Med* 14(1):13–17.

McCrory P, Meeuwisse WH, Aubry M, et al. (2013) Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med* 47(5):250–258.

Mohammed MT, Whitney SL, Marchetti GF, Sparto PJ, Ward BK, Furman JM. (2011) The reliability and response stability of dynamic visual testing of the vestibulo-ocular reflex in patients with vestibular disease. *J Vestib Res* 21(5):277–288.

Moyna NM, Robertson RJ, Meckes CL, Peoples JA, Millich NB, Thompson PD. (2001) Intermodal comparison of energy expenditure at exercise intensities corresponding to the perceptual preference range. *Med Sci Sports Exerc* 33(8):1404–1410.

Mucha A, Collins MW, Elbin RJ, Furman JM, Troutman-Enseki C, DeWolf RM, Marchetti G, Kontos AP. (2014) A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med* 42(10):2479–2486.

Murray NG, Ambati VNP, Contreras MM, Salvatore AP, Reed-Jones RJ. (2014) Assessment of oculomotor control and balance post-concussion: a preliminary study for a novel approach to concussion management. *Brain Inj* 28:496–503.

NeuroCom International, Inc. (2011) *Clinical Integration Manual, InVision System*. Clackamas, OR: NeuroCom International, Inc.

NeuroCom International, Inc. (2013) *VSR Sport: Play a Smarter Game*. http://www.playasmartergame.com/. Accessed September 20, 2013.

Notebaert AJ, Guskiewicz KM. (2005) Current trends in athletic training practice for concussion assessment and management. *J Athl Train* 40(4):320–325.

Onate JA, Beck BC, Van Lunen BL. (2007) On-field testing environment and balance error scoring system performance during preseason screening of healthy collegiate baseball players. *J Athl Train* 42(4):446–451.

Putukian M, Raftery M, Guskiewicz K, Raftery M, Guskiewicz K, Herring S, Aubry M, Cantu RC, Molloy M. (2013) Onfield assessment of concussion in the adult athlete. *Br J Sports Med* 47(5): 285–288.

Rahn C, Munkasy BA, Barry Joyner A, Buckley TA. (2015) Sideline performance of the balance error scoring system during a live sporting event. *Clin J Sport Med* 25(3):248–253.

Robertson RJ, Moyna NM, Sward KL, Millich NB, Goss FL, Thompson PD. (2000) Gender comparison of RPE at absolute and relative physiological criteria. *Med Sci Sports Exerc* 32(12): 2120–2129.

Susco TM, Valovich McLeod TC, Gansneder BM, Shultz SJ. (2004) Balance recovers within 20 minutes after exertion as measured by the balance error scoring system. *J Athl Train* 39(3):241–246.

Valovich McLeod TC, Hale TD. (2015) Vestibular and balance issues following sport-related concussion. *Brain Inj* 29(2):175–184.

van der Naalt J. (2001) Prediction of outcome in mild to moderate head injury: a review. *J Clin Exp Neuropsychol* 23(6):837–851.

Ward BK, Mohammad MT, Whitney SL, Marchetti GF, Furman JM. (2010) The reliability, stability, and concurrent validity of a test of gaze stabilization. *J Vestib Res* 20(5): 363–372.

Wilkins JC, Valovich McLeod TC, Perrin DH, Gansneder BM. (2004) Performance on the balance error scoring system decreases after fatigue. *J Athl Train* 39(2):156–161.

Williamson IJ, Goodman D. (2006) Converging evidence for the under-reporting of concussions in youth ice hockey. *Br J Sports Med* 40(2):128–132, discussion 128–132.

Zhou G, Brodsky JR. (2015) Objective vestibular testing of children with dizziness and balance complaints following sports-related concussions. *Otolaryngol Head Neck Surg* 152(6): 1133–1139.