The Gaze Stabilization Test Following Concussion

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Abstract

Background: Concussion can cause vestibular dysfunction and oculomotor abnormalities which can lead to dizziness and protracted recovery time. There are few clinically useful, functional measures of the vestibulo-ocular reflex (VOR) post-concussion.

Purpose: The purpose of this study is to examine the gaze stabilization test (GST) in those referred for vestibular physical therapy following concussion, to determine the association between the GST and other measures of recovery following concussion, and to examine the effect of demographic variables on GST performance.

Research Design: Retrospective chart review

Study Sample: 158 individuals who sustained a concussion and were referred to vestibular physical therapy.

Data Collection and Analysis: Horizontal and vertical GST scores (HGST and VGST), neurocognitive testing results, and demographic data were extracted retrospectively from the patient health record. Correlations between GST velocity and neurocognitive test results and between the GST and patient-reported outcomes were examined. Differences in GST performance among patient subgroups were examined using one-way ANOVA.

Results: Subjects included individuals aged 12 to 43 years ($M=20$, $SD=7$), with most having sport-related concussion (67%). The mean time from injury to GST was 215 days ($SD=241$) and mean time from physical therapy evaluation to GST was 48 days ($SD=54$). HGST and VGST had a weak positive correlation to the Activities-specific Balance Confidence Scale ($r=0.20$, $r=0.21$) and weak negative correlation to the Dizziness Handicap Inventory ($r=-0.18$, $r=-0.22$). HGST had a weak positive correlation to the visual motor processing speed domain of the Immediate Post-Concussion Assessment and Cognitive Test ($r=0.20$). Male patients achieved significantly higher velocities than female patients on horizontal and vertical GST ($p=.02$, $p=.01$).

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Conclusions: The present study details the use of the GST in patients with concussion and demonstrates an association with common outcomes measures in vestibular rehabilitation. Results indicate that patients who achieved higher velocities on GST perceived lower handicap due to dizziness and had higher confidence in their balance. The GST may be a relevant test of VOR in this population, as it is a more functional test of the VOR required for sports. Future work is needed to further evaluate the role of GST in concussion management.

Keywords

mTBI; mild traumatic brain injury; gaze stability; vestibulo-ocular reflex; vestibular rehabilitation

Introduction

Between 1.8 and 3.6 million concussions occur each year in the United States (Langlois et al., 2006). However, there is no uniform consensus on the best approach to measure and manage this injury (McCrory et al., 2017). Clinicians have measured signs and symptoms of concussion using on-field screening tests, self-report measures, and computerized neurocognitive testing (Kontos et al., 2012; Harmon et al., 2013). Dizziness is a common symptom reported by individuals who have sustained a concussion and has been associated with increased risk for protracted recovery time (Chamelian et al., 2004; Yang et al., 2007; Lau et al., 2011). Vestibular system impairments and oculomotor impairments have been found to occur in 20–90% of individuals following concussion and are common targets for treatment in individuals who receive vestibular physical therapy after concussion (Davies et al., 1995; Maskell et al., 2006; Ciuffreda et al., 2007). However, objective, functionally meaningful outcome measures of vestibular dysfunction that can be applied in the clinic are limited in this population.

The vestibular ocular reflex (VOR) stabilizes gaze during head movement. Participation and optimal performance in sports requires a well-functioning VOR and vestibular system (Kaufman et al., 2014). Functional measurements of the VOR that can be evaluated in a clinic include the dynamic visual acuity test (DVAT) and the gaze stabilization test (GST) (Herdman et al., 1998; Goebel et al., 2007). The DVAT assesses the smallest optotype size the patient can identify at a fixed voluntary head velocity range, usually 120–180 degrees per second (deg/s) (Goebel et al., 2007; Li et al., 2014). The GST measures the maximum voluntary rotational head velocity that can be attained while accurately identifying a fixed optotype size. Therefore, the GST largely evaluates functional impairment of the VOR at greater head velocities needed for participation in high level activities of daily living and sports. Computerized DVAT and GST performance has been found to be impaired in individuals with blast-induced head trauma (Gottshall et al., 2003; Gottshall et al., 2010). However, there is limited information available regarding the use of the GST in patients who have sustained a concussion. The GST may be a more relevant measure of functional VOR performance after concussion in individuals who must return to work or sport that require a high functioning vestibular system.

The purpose of this study was to retrospectively describe performance on the GST in a population of individuals with concussion, and to correlate these data with other measures of

recovery following concussion, including computerized neurocognitive data [The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT)] and self-report measures [Dizziness Handicap Inventory (DHI) and Activities-specific Balance Confidence Scale (ABC)]. The secondary aim of this study was to evaluate the effect of demographic variables and past medical history on the GST performance, which may be important to clinicians administering this test in individuals with concussion.

Methods

This retrospective chart review was approved by the Institutional Review Board at the University of Pittsburgh as an exempt study. The study included 158 individuals diagnosed with concussion by a healthcare provider at the UPMC Concussion Program, who were referred for vestibular physical therapy and underwent GST as part of routine clinical care from January 2012 to December 2012. The patients were evaluated at UPMC Centers for Rehab Services Balance Disorders Clinic or UPMC Center for Sports Medicine sites. All patients were enrolled in a course of vestibular rehabilitation and were treated with a customized exercise program developed by one of the investigators (PD, AM, or DS). The treating physical therapist determined when during care, it was appropriate to complete the GST based on individual patient presentation and was typically administered when the patient was nearing discharge.

The NeuroCom InVision Tunnel System (NeuroCom International, Inc., Clackamas, OR, USA) equipment was used for testing in a testing environment that has been described previously (Mohammad et al., 2011). Testing began by evaluating static visual acuity (SVA) and minimum perception time (mPT) to ensure adequate vision ($SVA < +0.3$ LogMAR) and visual processing (mPT < 40 ms) (Mohammad et al., 2011). Subjects were tested with their best corrected vision and were asked to return with their corrective lenses or contacts if SVA was greater than $+0.30$ LogMAR. The test was discontinued if mPT was greater than 40 ms to ensure patients did not substitute other visual systems for VOR (Mohammad et al., 2011). The patient was allowed to practice head movements in both yaw and pitch directions. A maximum of five optotype presentations were provided at each velocity range. The velocity was increased to the next range if the patient responded correctly for three out of five trials until the maximum head velocity was achieved (Goebel et al., 2007). The velocity ranges were 60–99, 100–139, 140–179, 180–219, and 220+ deg/s. Subjects began either at 60–99 or 100–139 deg/s, based on their performance during practice. The test-retest reliability of the InVision GST using the default Parameter Estimate by Sequential Testing algorithm has been reported to range from 0.62 to 0.79 in a healthy population and 0.25 to 0.48 in individuals with vestibular disease (Ward et al., 2010; Mohammad et al., 2011). The algorithm used for determining the GST velocity in this study was based on experimentally determined parameters that would facilitate efficient clinical testing; however, the reliability of this method has not been established (Mohammad et al., 2013). Subjects were asked to verbally rate their symptoms of headache, dizziness, and nausea on a scale from 0 to 10 by the physical therapist before testing and after both horizontal and vertical GST.

Demographic data, such as gender and age, history of present illness, past medical history, and computerized neurocognitive test data were obtained from each patient's electronic

medical record. Gender was of interest because there are known differences in symptom report and Vestibular Ocular Motor Screening (VOMS) among men and women (Sufrinko et al., 2017). The effect of age was examined because previous studies have found differences in GST performance (Gottshall et al., 2010; Ward et al., 2010). History of migraine, ocular misalignment, learning disability, and motion sensitivity were determined by patient self-report. Concussion injuries were classified as subacute if time from injury was over 72 hours up to 3 months and as chronic if time from injury was greater than 3 months as specified by the National Institute of Neurological Disorders and Stroke Sport-Related Concussion Common Data Elements (Grinnon et al., 2012).

ImPACT is a widely used computerized neurocognitive test that has been validated as an evaluative tool in sports-related concussion (Iverson et al., 2005; Iverson et al., 2006; Sandel et al., 2013). This neurocognitive assessment examines the following domains: verbal memory, visual memory, visual motor processing speed, and reaction time. This test evaluates patient-reported symptoms through the included 22-item Post-Concussion Symptom Scale (PCSS). ImPACT and PCSS scores were collected from the test completed closest to the date of GST performance and reviewed by a neuropsychologist within the UPMC Concussion Program. Only ImPACT and PCSS data within two weeks of the date of GST completion was used for comparison to GST. GST results, symptom report, and patient reported outcome measures at the time of GST were obtained from the vestibular rehabilitation chart. Outcome measures included the DHI and ABC, which are valid and reliable patient-reported outcome measures commonly used in vestibular rehabilitation (Jacobson et al., 1990; Powell et al., 1995). While there is limited available data on the reliability and validity of the DHI and ABC in adolescents with concussion, these measures have been used previously in this population (Alsalaheen et al., 2010; Alsalaheen et al., 2016).

Data Analysis

The average GST velocity for each direction (left, right, up, and down) was calculated by taking the average of the top 3 highest achieved speeds where the subject correctly identified the optotype. Then, the average of head velocity for the right and left was calculated to obtain overall horizontal velocity. The same was done for overall vertical head velocity by averaging top velocities in up and down directions. Average calculations of top velocities were performed to determine the highest speed each patient was able to consistently identify the optotype (Ward et al., 2010). Pearson's correlation was used to evaluate the relationship between overall horizontal and vertical head velocity and demographics and ImPACT data. Spearman's correlation was used to examine the relationship between horizontal and vertical velocities and overall PCSS scores, ABC, DHI, and change in symptom from pre-test to post-test.

Differences between male and females, subacute and chronic injuries, professional athletes and non-professional athletes, and individuals with and without history of migraine, motion sensitivity, learning disability, and ocular misalignment were examined using an independent samples t-test. The effect of age was examined using a one-way analysis of variance (ANOVA) for specified age groups (<20, 20–30, and >30 years old).

Results

This retrospective chart review details the performance of 158 individuals aged 12–43 years ($M=20$, $SD=7$) who sustained a concussion (Table 1). The majority of the subjects in the sample were male (57%) and concussed from a sport-related injury (67%). The most common sports played were football (19%), hockey (11%), soccer (9%), basketball (8%), and cheerleading (6%). Other mechanisms of injury included falls, motor vehicle accidents, and work accidents. Interestingly, almost half of the subjects had a history of a previous concussion. The most common comorbidities reported were history of motion sensitivity and history of migraine. The time between concussive injury and physical therapy evaluation was highly variable (median=70 days). GST was examined 48 days ($SD = 54$) after the initial physical therapy evaluation, on average (Range = 0–356 days).

Overall, the sample achieved greater GST velocities in the horizontal direction ($M=237$, $SD=34$ deg/s) compared to the vertical direction ($M=208$, $SD=35$ deg/s), ($p < 0.001$) (Table 2). Also, the average GST velocity in the left direction was about 4 deg/s greater than the right direction ($p<0.001$). Average GST in the down direction was significantly greater than the up direction by about 18 deg/s ($p<0.001$).

At the time of GST, ABC scores were almost perfect, indicating high confidence in balance ability, and DHI scores were in the mildly impaired range of perceived handicap (Table 3). There was a weak relationship between horizontal and vertical head velocities and ABC score (HGST, $r=0.20$; VGST, $r=0.21$) and weak negative correlation to DHI score (HGST, $r=-0.18$; VGST, $r=-0.22$). This indicates that greater GST velocity in each direction was associated with higher balance confidence and lower perceived handicap due to dizziness in our sample, although these relationships were weak. There were no significant correlations between PCSS score and horizontal and vertical head velocities. On average, GST was performed within 4 days of ImPACT ($M=3.6$, $SD=4.4$, Range=0–13 days). ImPACT taken closest to time of GST demonstrated a weak positive correlation between visual motor processing speed percentile scores and horizontal GST ($r=0.24$).

Comparison of overall velocity in the horizontal direction revealed significantly higher velocity in males ($M=242$, $SD=33$) compared with females ($M=229$, $SD=33$, $p=.02$). Similarly, overall velocity in the vertical direction was significantly higher in males ($M=215$, $SD=38$) than females ($M=200$, $SD=29$, $p=.01$). Individuals with subacute injury (3 days – 90 days) and chronic/persistent symptoms (greater than 90 days) did not have any significant differences in GST performance. There were no significant differences in GST between individuals with and without a history of learning disability, migraine, or motion sensitivity. Also, there were no significant differences in velocity between professional and non-professional athletes, or among the specified age groups. There were no significant correlations between age, time from injury, number of prior concussions and GST.

Discussion

The primary aim of this study was to describe GST performance and evaluate the association between GST and other measures of recovery in individuals with concussion who received

vestibular physical therapy. To our knowledge, this is the first study examining the relationship between GST and commonly used outcomes when treating patients with concussion. We found that horizontal and vertical GST had a weak correlation with the ABC and a weak negative correlation with the DHI in this population. Also, there was a weak correlation between horizontal GST and the visual motor processing speed domain within ImPACT. Currently, the GST is used in the vestibular rehabilitation clinic as a functional measure of VOR in patients with vestibular disorders and head injury (Gottshall et al., 2003; Badaracco et al., 2007; Gottshall et al., 2010). We feel that the present study details the use of the GST in patients with concussion and assesses functional VOR which may inform changes in treatment protocol or decisions regarding return to play in this population.

The mean velocity for horizontal and vertical head movements are somewhat faster than previously reported in similarly aged healthy samples, in which subjects produced horizontal GST velocities ranging from 104 to 169 deg/s (Pritcher et al., 2008; Ward et al., 2010; Honaker et al., 2015). Kaufman et al. (2014) and Schneiders et al. (2010) reported similar GST velocities in their samples of football players and motor sport athletes (Schneiders et al., 2010; Kaufman et al., 2014). Gottshall et al. (2010) reported 200 deg/s as a normative value for healthy individuals aged 20–30 years old. In our sample, the majority of the subjects achieved GST velocities higher than 200 deg/s in horizontal (87%) and vertical (58%) directions, indicating normal performance in over half of the sample. Gottshall et al. (2010) went on to study a sample of individuals with blast-induced head trauma and found that GST did not return to normal velocities after 8 weeks of vestibular rehabilitation but achieved normal velocities after 12 weeks of physical therapy. Our sample of patients demonstrated similar velocities to the proposed normative values after an average of 48 days (about 7 weeks) enrolled in vestibular physical therapy.

Average horizontal and vertical GST velocities were higher among male patients. There is evidence that suggests that female athletes have higher symptom reports with PCSS and increased symptoms while performing VOR during the VOMS after sport-related concussion (Sufrinko et al., 2017). Female patients in this sample did not report higher PCSS symptoms at the time of GST, but they did have worse performance on horizontal GST which aligns with previously described difficulties on the VOR component of the VOMS (Sufrinko et al., 2017). There was a higher percentage of history of migraine among females in our sample, which potentially had an effect on GST performance, as VOR abnormalities have been found in persons with migraine headaches (Helm, 2005; Sufrinko et al., 2017). This has an important clinical implication such that clinicians should not expect female patients to achieve the same velocities as males when assessing the GST during rehabilitation. There was no significant difference among age groups, which has been previously reported (Gottshall et al., 2010; Ward et al., 2010). Gottshall et al. (2010), used different normative speeds when comparing subjects with head injury ages 20, 30, and 40 years old, similar ages to our sample. Ward et al. (2010), compared young and old adults and found a significant difference in GST performance in horizontal and vertical directions. When comparing GST velocity in individuals with and without pre-morbid reports of migraine, motion sensitivity, and learning disability, there were no significant differences. Based on these results, clinicians should not expect patients between ages 12–40 or with a self-reported history of motion sensitivity, migraine, or learning disability to perform differently on GST.

The sample completed the GST on average 6–7 weeks after initial evaluation in vestibular physical therapy and a median of 10 weeks after injury, indicating a relatively prolonged recovery period. Overall, the patients were nearly asymptomatic at the time of GST, indicated by pre-test symptoms and self-report measures (PCSS, DHI, and ABC). The mean DHI score was 11 and the ABC score was 95, suggesting that most of the subjects has close to normal scores on both subjective ratings. However, the ABC has demonstrated a ceiling effect in healthy adolescents, meaning there may have been balance impairments that this measure did not capture (Alsalaheen et al., 2014). Similarly, previous findings indicate that children have better (lower) DHI scores than adults which could have influenced the mean score in this sample (Alsalaheen et al., 2010). The correlation between GST and DHI and ABC indicates that a better functioning VOR is associated with higher balance confidence and lower perceived handicap due to dizziness in this sample, although the strength of the correlations was weak. Previous studies have identified that DVAT findings and the DHI are correlated in patients with concussion (Gottshall et al., 2003).

We found a small correlation between horizontal head velocity and the ImPACT visual motor processing speed domain. Collins et al. has noted that patients falling into the proposed vestibular trajectory following concussion may have difficulty on the visual motor processing speed and reaction time domains and relatively normal memory performance (Collins et al., 2014). While there is a visual processing component to the GST, the mPT test administered in the beginning of the test is used to ensure adequate visual processing speed. If the mPT was greater than 40ms, the GST was not continued. Because the GST is a psychophysical test, visual motor processing speed is likely a component of the performance. Thus, the correlation between GST and visual motor processing speed may be clinically important and impairments on these tests may indicate a need for vestibular rehabilitation following concussion.

There are several limitations to the present study. First, the retrospective nature of this chart review leads to limited control over data collection methods and the completeness of the data set. Thus, we were only able to include GST at one time-point when the clinician chose to evaluate the test during the course of rehabilitation. The lack of variability of symptom report and patient-reported outcomes in our sample likely affected the magnitude of correlations between GST and these measures. The majority of patients achieved head velocities greater than 150 deg/s, indicating high performance by suggested normative values. Finally, the technique used to measure GST in this sample was slightly different than those previously reported and did not utilize the Neurocom parameter estimate by sequential testing algorithm (Goebel et al., 2007; Mohammad et al., 2013). Ward et al. (2010) commented on the lack of tester control when using the algorithm because it does not differentiate from a trial failure versus inability to accurately visualize the target during head movement. However, further research is needed to determine the reliability of the method of GST used in the present study.

Conclusions

The difference found for GST velocities between genders has utility when evaluating GST in the clinic. Although the correlations between the GST, ABC, and DHI were weak, this study

demonstrates the benefit of using the GST in vestibular rehabilitation settings in a concussed population as there is a relationship to functional perception of balance and dizziness. The relationship between horizontal GST and visual motor processing speed may be important when evaluating and treating patients who fall into the proposed vestibular trajectory following concussion. Further evaluation of patients in different stages of recovery from concussion will be required to determine an accurate correlation between performance-based and patient-reported outcomes and GST. The GST is a functional measure of VOR and may be a valuable tool in determining readiness for discharge from vestibular physical therapy and perhaps return to play. However, future work is needed to determine the role for GST in evaluation and management of concussion.

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Abbreviations:

VOR	vestibulo-ocular reflex
GST	Gaze Stabilization Test
DVAT	Dynamic Visual Acuity Test
SVA	static visual acuity
mPT	minimum perception time
VAS	Visual Analogue Scale
ImPACT	Immediate Post-Concussion Assessment and Cognitive Test
PCSS	Post-Concussion Symptom Scale
DHI	Dizziness Handicap Inventory
ABC	Activities-Specific Balance Confidence Scale
M	mean
SD	standard deviation
HGST	horizontal Gaze Stabilization Test
VGST	vertical Gaze Stabilization Test
VOMS	Vestibular Ocular Motor Screening

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Table 1.

Descriptive statistics for sample demographics, history of present illness, and past medical history

	Total sample N = 158
Mean age, y (SD), [Range]	20 (7), [12–43]
Male gender, n (%)	90 (57)
Sport-related mechanism of injury, n (%)	105 (67)
Professional athlete, n (%)	15 (10)
Previous concussion, n (%)	63 (44)
History of motion sensitivity, n (%)	71 (45)
History of migraine, n (%)	47 (30)
History of learning disorder, n (%)	14 (9)
History of ocular misalignment, n (%)	7 (4)
Mean time from injury to PTEVAL, days (SD), [Range]	173 (238), [4–1430]
Mean time from injury to GST, days (SD), [Range]	215 (241), [26–1619]
Mean time from PTEVAL to GST, days (SD), [Range]	48 (54), [0–356]

Abbreviations: PTEVAL, physical therapy evaluation; GST, gaze stabilization test

Table 2.

Descriptive statistics for gaze stabilization test (GST) parameters, maximum achieved head velocity, and symptom report

	Mean (SD) [Range]
Static visual acuity (logMAR) (n = 156)	−0.06 (0.12) [−0.26–0.40]
Minimum perception time (ms) (n = 156)	21.7 (4.1) [20–40]
Average left GST velocity (deg/s) (n = 154)	239 (33) [132–323]
Average right GST velocity (deg/s) (n = 144)	235 (40) [104–361]
Average horizontal GST velocity (deg/s) (n = 154)	237 (34) [135–322]
Average down GST velocity (deg/s) (n = 125)	216 (37) [119–302]
Average up GST velocity (deg/s) (n = 102)	198 (39) [90–293]
Average vertical GST velocity (deg/s) (n = 125)	208 (35) [112–286]

Abbreviations: GST, Gaze Stabilization Test

Table 3.

Outcome measures and correlation (p-value) with gaze stabilization test (GST) head velocity in horizontal and vertical directions

	Mean (SD)	Correlation coefficient for horizontal GST	Correlation coefficient for vertical GST
ABC (n = 129)	96 (10)	0.20 * (p = 0.021)	0.21 * (p = 0.028)
DHI (n = 127)	12 (14)	-0.18 * (p = 0.045)	-0.22 * (p = 0.027)
PCSS (n = 115)	11 (13)	-0.13	-0.079
ImPACT (n = 116)			
Verbal Memory %	61 (31)	0.019	-0.049
Visual Memory %	54 (32)	0.012	0.002
Visual Motor Processing	62 (31)	0.24 * (p = 0.03)	0.087
Speed %			
Reaction Time %	56 (30)	0.072	0.034

* p < 0.05

Note: Spearman rank correlation coefficient used to examine relationship between GST and ABC, DHI, and PCSS; Pearson correlation coefficient used to examine relationship between GST and ImPACT percentile scores

Abbreviations: ABC, Activities-specific Balance Confidence Scale; DHI, Dizziness Handicap Inventory; PCSS, Post-Concussion Symptom Scale; ImPACT, Immediate Post-Concussion Assessment and Cognitive Test