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A NOVEL APPROACH TOWARD CONCUSSION TESTING

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Abstract

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A concussion is a violent jarring or shaking of the head caused by whiplash or direct impact that results in a disturbance of brain function. Concussions can be mild and brief, as a person may be dazed momentarily or can be more serious, resulting in a loss of consciousness. Underreporting of concussions is prevalent because they are a symptom-based diagnosis, lacking a clinical test. In this study, we investigated the use of VNG testing as a clinical diagnosis of concussions. Looking at the VNG test battery, the previous research cohort found that saccades, gaze, and positional testing are the most sensitive identifiers of concussion when looking for the presence of microsaccades, which are small jerky eye movements that occur when fixating on a stationary image. By grouping these 3 most sensitive tests into a 3-test cluster, they found that 78% of true concussion patients (155 subjects) demonstrated abnormal microsaccades in one of these three tests. We studied subjects without a history of concussion for presence of microsaccades in order to determine specificity of these tests. Of the 64 subjects screened and included in the study for this group, none of the subjects demonstrated evidence of abnormal microsaccades in the 3-test cluster. As a result, we conclude that our 3-test VNG cluster can potentially produce a moderately sensitive, highly specific screening for patients suspected of having a concussion.

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INTRODUCTION

In the United States, according to the Centers for Disease Control and Prevention, each year 2.8 million people present to a hospital emergency room with a concussion, also called a mild traumatic brain injury (mTBI) (Taylor et al., 2017). Identification of individuals who suffer a concussion is complicated by many factors. Conventional imaging (CT and MRI) is normal by definition, and most currently utilized methods rely on the clinician's ability to identify observed signs and the truthfulness of the subject. A growing amount of research suggests that certain abnormal eye movements may occur in individuals after sustaining an mTBI (Tjarks et al., 2013; Bin Zahid et al., 2020). Tjarks et al. 2013 compared the King-Devick Test, which measures oculomotor function based on the testing of saccadic eye movements, with two mTBI subjective diagnostic tests regarded to have high sensitivity/specificity (the ImPACT test and the PCSS test). The research found that there was a correlation between these tests and that King-Devick can be a useful diagnostic tool (Tjarks et al., 2013). A pilot study conducted by the Sports Medicine, Rehabilitation, and Concussion Center included 120 subjects who were previously diagnosed with an mTBI and found that subjects with elevated microsaccades took longer to recover (Bin Zahid et al., 2020).

Microsaccades are small, jerky eye movements that occur when fixating on a stationary image. They precisely relocate gaze toward nearby areas of interest in high acuity visual tasks (Poletti and Rucci, 2016). Microsaccades are often involuntary but can be voluntarily executed also during sustained fixation, perhaps to compensate for fixation errors (Poletti and Rucci 2016). On average, an individual executes about 1 - 2 microsaccades per second; greater than 2 microsaccades per second is considered abnormal (Panagiotidi et al., 2017) and these abnormal microsaccades are the biomarkers we examined in this study.

Videonystagmography (VNG) testing uses an infrared camera to assess eye movements (Flint, 2020). For this study patients underwent a battery of tests including: smooth pursuit, saccades, optokinetic, gaze testing, spontaneous nystagmus, torsion Swing testing, active head-rotation testing, and positional testing. VNG testing is traditionally used to diagnose vestibular disorders such as benign paroxysmal positional vertigo (BPPV), vestibular neuritis, and Meniere's disease (MedTrak, 2012). In our experiment we examined whether abnormal microsaccades are present during any of the specific tests in the VNG test battery.

The purpose of our research was to investigate if abnormal microsaccades identified during Videonystagmography testing are correlated with concussion history. If correlation existed, an additional goal was to identify which VNG tests have the highest sensitivity in eliciting abnormal microsaccades to guide clinical practice and focus further research study in this area. We analyzed the data of patients who had already undergone a VNG test for an unrelated reason to determine if factors such as age, gender, number of mTBIs, and time between injury and testing also had influence on the prevalence of abnormal microsaccades.

MATERIALS AND METHODS

Subjects were recruited from two VNG testing facilities. The most common reasons for referral were generalized dizziness and concussion. Inclusion criteria included patients being referred out for VNG testing and a willingness to participate in this study. When the subjects signed the paperwork related to their VNG test they were asked for their consent to have their VNG results included in this study.

The experimental protocol was approved by the Institutional Review Board (IRB) of the CUNY-wide committee (IRB No:2019-0647). A total of 219 people, between the ages of 14 and 81, participated in this study. Of these 219 subjects, 64 reported no history of concussion while 155 reported a history of concussion. The subjects in the experimental group had previously been diagnosed with concussion by their physicians and had been referred for a VNG test as part of their plan of care. Of the 155 participants included in the experimental group, the average age was 40 and the average number of days between injury and testing was 261. The control group consisted of 64 subjects, 21 were male and 43 were female, with an average age of 56. All of these subjects reported no history of a concussion during screening. All subjects were stratified into 7 age related categories for data analysis.

Subjects reported information to the research group including gender, age, history of neurological disease, and concussion history. The presence of abnormal microsaccades was detailed for each of the 10 tests of the VNG. These tests included: Tracking / Smooth Pursuits, Saccades, Optokinetic, Gaze Testing, Spontaneous Nystagmus, Torsion Swing, Active Head Rotation, Positional Tests (Supine Head Center, Supine Head Left, Supine Head Right, Body Left, Body Right), Dix Hallpike and Caloric testing.

RESEARCH DESIGN AND PROCEDURE

The research design of this study was a cross-sectional study. Subjects were stratified into subgroups based on history of concussion, time since the most recent injury, age, and gender to assess test sensitivity in different populations. The time since injury was stratified into 8 groups: <30 days, 31-60 days, 61-100 days, 101-200 days, 201 to 365 days, 1-2 years, 2-3 years, and greater than 3 years. Participants were also stratified by age into 7 categories based on the following age ranges: 14-20 years old, 21-30, 31-40, 41-50, 51-60, 61-70, and 71-80 years of age. Once the data was cataloged, sensitivity was calculated for each of the 10 tests of the VNG battery individually using the total sample size, as well as each specific subgroup.

Sensitivity was determined for each sub group within the experimental group for each VNG test using the formula: Sensitivity=True Positives/(True Positives+False Negatives). The control group, which includes those without a history of concussion, was used to determine specificity by reviewing the results of all tests in the VNG battery for the presence of abnormal microsaccades. Specificity was determined for each VNG test using the formula: Specificity=True Negatives/(True Negatives+False Positives). Afterwards, sensitivity was calculated for our 3 most sensitive tests combined in a 3-test cluster.

The VNG test battery was evaluated by a computer algorithm and the results confirmed by a Board-Certified Neurologist. Our research team then categorized the results into a Microsoft Excel spreadsheet. This spreadsheet listed the subject number, gender, age, number of days between injury and VNG test, number of self-reported concussions, and the presence or absence of abnormal microsaccades for each of the tests of the VNG battery.

RESULTS

		Gaze testing	Sensitivity
		83	54%
Gender	Male	43	51%
	Female	40	56%
Age	14-20	4	44%
	21-30	23	58%
	31-40	23	66%
	41-50	12	46%
	51-60	14	50%
	61-70	6	40%
	71-81	1	50%
Chronicity	<30 days	9	64%
	31-60	3	21%
	61-100	17	71%
	101-200	18	56%
	201-365 (1 year)	18	51%
	366-730 (2 years)	13	48%
	731-1095 (3)	4	67%
	>1096	1	33%
# of concussions	1	74	52%
	2 and above	9	69%

Table 1 Gaze Testing Sensitivity by Gender, Age, Chronicity & Concussion History

Of all of the tests in the VNG battery, the Gaze Test demonstrated the highest sensitivity. With regards to gender, both males and females exhibited similar sensitivity numbers, with 51% and 56% respectively. Those aged between 31-40 years demonstrated a sensitivity of 66%. The most notable trend however was seen within the time between injury and testing variable for the Gaze Test. When testing took place between 61 days and 100 days after injury, the sensitivity for abnormal microsaccades within gaze testing was 71%. Though our sensitivity did drop after 100 days, it remained above 51% sensitivity up until a year after injury. Participants who had suffered multiple concussions demonstrated a higher sensitivity of abnormal microsaccades within the Gaze Test (69%) when compared to the no previous history of concussion group (52%). However, this finding's significance is called into question as the multiple concussion group had a sample size of only 13 participants. No other major trends were of note within our data for the Gaze Test.

		Saccades test	Sensitivity
		47	30%
Gender	Male	22	26%
	Female	25	35%
Age	14-20	6	67%
	21-30	16	40%
	31-40	9	26%
	41-50	8	31%
	51-60	4	14%
	61-70	4	27%
	71-81	0	0%
Chronicity	<30 days	3	21%
	31-60	7	50%
	61-100	5	21%
	101-200	9	28%
	201-365 (1 year)	13	37%
	366-730 (2 years)	8	30%
	731-1095 (3)	2	33%
	>1096	0	0%
# of concussions	1	42	30%
	2 and above	5	38%

Table 2 Saccades Sensitivity by Gender, Age, Chronicity & Concussion History

		Positional Tests	Sensitivity
		33	21%
Gender	Male	20	24%
	Female	13	18%
Age	14-20	0	0%
	21-30	12	30%
	31-40	10	29%
	41-50	5	19%
	51-60	4	14%
	61-70	2	13%
	71-81	0	0%
Chronicity	<30 days	2	14%
	31-60	3	21%
	61-100	6	25%
	101-200	7	22%
	201-365 (1 year)	9	26%
	366-730 (2 years)	5	19%
	731-1095 (3)	0	0%
	>1096	1	33%
# of concussions	1	31	22%
	2 and above	3	23%

Table 3 Positional testing Sensitivity by Gender, Age, Chronicity & Concussion History

After the Gaze Test the next two most sensitive tests for abnormal microsaccades were the Saccade Test and the Positional Test. Females and males again showed similar sensitivity numbers for these two VNG tests. A trend is noticed within the younger age groups for both tests. For the Saccade Test, a sensitivity of 67% was shown between the age group of 14-20 years old. As age increases to 21-30 years old, the sensitivity drops to 40% and continues to drop below 40% for every age group above 30. For the Positional Test, the highest sensitivity for age is observed between the ages of 21-30 years old with 30% sensitivity, and 31-40 years old with 29% sensitivity. As age progresses, sensitivity continues to drop for positional testing. For the Saccade Test a trend is noticed between 31-60 days of testing. The sensitivity for this specific variable was 50% for detecting abnormal microsaccades. All other sensitivity numbers for this variable and test were considerably less than 50%.

		1/3 cluster	1/3 cluster sensitivity
			78%
Gender	Male	64/84	76%
	Female	57/71	80%
Age	14-20	7/9	78%
	21-30	34/40	85%
	31-40	30/35	86%
	41-50	21/26	81%
	51-60	17/28	61%
	61-70	11/15	73%
	71-81	1/2	50%
Chronicity	<30 days	11/14	79%
	31-60	11/14	79%
	61-100	19/24	79%
	101-200	26/32	81%
	201-365 (1 year)	26/35	74%
	366-730 (2 years)	22/27	81%
	731-1095 (3)	5/6	83%
	>1096	1/3	33%
# of concussions	1	109/142	77%
	2 and above	12/13	92%

Figure 1 Three test cluster Sensitivity by Gender, Age, Chronicity & Concussion History

After analyzing the sensitivity for each test individually we analyzed the percentage of subjects who demonstrated abnormal microsaccades during any of our top 3 tests which we will refer to as our 3-test cluster (gaze, saccadic, and positional testing). This is similar to diagnostic test clusters utilized for diagnosis of orthopedic injuries. We found that 77% of all subjects demonstrated abnormal microsaccades during at least 1 of this 3-test cluster Even though only 13 subjects identified as having a previous concussion, 12 of them (92%) demonstrated abnormal microsaccades with our 3-test cluster.

None of the subjects in the control group had a presence of abnormal microsaccades in any of the tests in the VNG battery, resulting in 100% specificity for each test.

DISCUSSION

The top three most sensitive tests in our study were the Gaze Test, Saccade Test, and the Positional Test. There are three potential reasons why these tests may have been the most sensitive. From the data the authors speculate that the longer a static position is held, the more likely abnormal microsaccades will be identified on testing. For instance, the Gaze Test requires the subject to look for 25 seconds in each direction (Up, Down, Left, Right), The Saccade Test requires the subject to look for 2 seconds at a time in each direction, and the Positional Test requires the subject to look in one direction for 25-30 seconds. Other VNG tests involve more continuous movement which may account for the relatively higher sensitivity of these 3 tests. Another possibility is that abnormal microsaccades are more likely present with the eyes looking in one direction versus another, or they may be brought on more readily in different positions. The last possibility is that abnormal microsaccades may be influenced by the patient focusing their gaze on a target as opposed to not focusing on a target. This phenomenon is seen when attempting to screen for nystagmus in Benign paroxysmal positional vertigo (BPPV) where a patient's visual fixation may override the nystagmus in the Dix-Hallpike position.

By grouping our 3 most sensitive tests into a 3-test cluster, (The Gaze Test, Saccade Test, and Positional Test) we found that 78% of true concussion patients demonstrated abnormal microsaccades in one of these three tests. In the control group, none of the subjects demonstrated evidence of abnormal microsaccades in our 3-test cluster (gaze, saccadic, and positional testing.) Considering that none of the patients without concussion demonstrated abnormal microsaccades during any of the VNG tests it adds strength to the argument that the presence of abnormal microsaccades is indicative of concussion. Hence, our 3-test cluster potentially represents a quick, fairly sensitive and highly specific form of first line screening for patients suspected of sustaining a concussion.

When looking at the difference in overall positive findings between our one concussion group and multiple concussions group, all 13 participants in the multiple concussions group had a positive finding for abnormal microsaccades on at least one test. In our 3-test cluster, the multiple concussion group demonstrated 92% sensitivity. This data tentatively suggests that test sensitivity increases in individuals who have experienced more than one concussion. This finding is significant for future research as investigators can more efficiently focus their efforts with these 3 tests instead of performing the entire VNG.

Males and females had a similar incidence of abnormal microsaccades on at least one test (85% for males and 90% for females). While there were small differences in sensitivity for individual tests, gender seems to have a minimal effect on test sensitivity when VNG is performed as a diagnostic cluster.

Since only 3 of our subjects with concussion were evaluated within 30 days, further studies which focus on subjects with acute mTBI needs to be performed. The author's suspicion is that there is higher sensitivity in the initial days after mTBI and that these findings fade with increased time.

LIMITATIONS

The small sample size of the multiple concussions group. Only 13 of our study participants had a documented history of more than one concussion. The small sample size of the control group was another limitation.

Another study limitation was that subjects may have suffered a concussion without knowing it.

Finally, it should be noted that we did not adequately study if abnormal microsaccades were present in people with a history of known neurologic dysfunction due to our sample, which contained one subject with a history of encephalitis and two subjects with a history of CVA.

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