Analysis of Central and Peripheral Vision Reaction Times in Patients With Postconcussion Visual Dysfunction

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Objective: To determine whether central and peripheral vision reaction times (PVRTs) are prolonged in patients with visual dysfunction after sustaining a concussion.

Design: Comparison of Dynavision D2 central and PVRTs in patients with postconcussion visual dysfunction were compared with control data from a normative patient database. Concussion patients without visual dysfunction were not included in this study.

Setting: National Collegiate Athletic Association Division 1 college training room and university based, academic health center.

Participants: Patients were selected for inclusion based on diagnosis of new visual dysfunction as indicated either by physical examination of the team physician or by patient self-report of symptoms. Patients included college athletes, college students, and concussion patient's presenting to a university based, academic health center.

Intervention: Measurement of central and PVRTs using a Dynavision D2 reaction time program were used as the dependent variables. Evaluations were conducted from 3 days to 11 months postconcussion, depending on the temporal development of visual symptoms after the concussion. No intervention was used.

Main Outcome Measures: Average central and PVRTs for patients with postconcussion visual symptoms were compared with an asymptomatic control group with no history of concussion.

Results: Both central and PVRTs were significantly prolonged in patients with postconcussion visual symptoms compared with patients with no history of concussion.

Conclusions: Central and PVRTs are both prolonged in patients with postconcussion visual dysfunction with PVRT being disproportionately prolonged. The percent change from central to PVRT was also increased in patients with postconcussion visual dysfunction.

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INTRODUCTION

There are an estimated 3.8 million concussions per year in the United States.[1] Common postconcussive symptoms include headache, dizziness, sleep disturbance, memory dysfunction, visual dysfunction, and general mental fogginess, among others. By their nature, these symptoms are inherently difficult to objectively quantify and even more difficult to follow longitudinally.[2]

New visual symptoms may develop after a concussion.[2,3] Furthermore, recent studies have found that visual sensory symptoms may be indicators of concussion and are useful in aiding in concussion management.[2,4,5] These visual symptoms include central field vision dysfunction, such as double vision or blurry vision and abnormal peripheral vision, among others.[6] Although all of these are concerning, peripheral vision has major implications not only on patient performance but also patient safety including sports-related return-to-play decisions.[7–9] Peripheral vision plays an important role in protecting athletes from impending impacts because they must see and react to events in their periphery.[9–12] Similarly, peripheral vision plays an important role in the safety of the general population in many of their activities of daily living; perhaps the most notable of these is driving.[8,10,13,14]

Interestingly, visual dysfunction has been associated with patient reports of feeling slower than normal.[3] This relationship, visual dysfunction and feeling slower than normal, implies that there may be an association between visual dysfunction and a patient's sense of timing, specifically reaction timing, in patients who have sustained a concussion. Slowed reaction time may be considered a risk for athletes when returning to play because of an increased likelihood of reinjury. This broadens the implications of monitoring reaction time, not only as a marker of when a patient is symptom free but also when a patient is safe to return to play. Because slowed reaction times have been documented in patients with concussion,[15] it is reasonable to infer that this may be a useful indicator of concussion. Current return-to-play guidelines rely heavily on patients' self-report of symptoms.[1,16] An inherent flaw with this subjective system is that certain populations may be incentivized, consciously or unconsciously, to minimize the reporting of symptoms. There is a need

for a method to assess a patient's concussion symptoms to aid in objectively after a patient's recovery over time.

The aim of this pilot study is to determine whether central vision reaction time (CVRT) and peripheral vision reaction time (PVRT) are prolonged in patients with postconcussion visual symptoms. We hypothesize that CVRT and PVRT will be prolonged in patients who have sustained a concussion and have new visual dysfunction.

METHODS

After Institutional Board Review (IRB) was obtained, the records of 23 concussion patients with postconcussion visual symptoms who underwent Dynavision D2 (D2) (Dynavision International LLC, Cincinnati, Ohio, USA) evaluations with central and PVRT assessments were examined retrospectively. The D2 evaluation of both CVRT and PVRT is a routine component of our postconcussion evaluations, therefore, a waiver of informed consent was approved by the IRB.

Only patients who demonstrated new visual dysfunction postconcussion were included in this study. All the postconcussion visual dysfunction patients were diagnosed by a single practitioner, the University of Cincinnati team physician (J.G.D.). Patients were determined to have postconcussion visual dysfunction either by physical examination of the team physician (J.G.D.) or by patient self-report of symptoms (Table 1). D2 evaluations were conducted from 3 days to 11 months postconcussion, depending on the temporal development of visual symptoms after the concussion. The postconcussion visual dysfunction group included 11 males and 12 females with a mean (±SD) age of 30.2 ± 15.2 years. Patients who sustained a concussion, but did not have secondary visual symptoms, were not included in this study. A control group of 30 healthy subjects was selected from patients who had undergone the same D2 evaluations with both CVRT and PVRT assessments as the concussion group. The control group patients had no previous history of concussion or other form of traumatic brain injury. The mean age of the control group was 26.5 ± 10.3 years. All Dynavision D2 reaction time evaluations were performed by a single practitioner (J.F.C.).[17]

TABLE 1. Summary of Initial Symptoms in the Concussion Group, With Visual Symptoms, Based on Patient Report

Symptom	Frequency (N = 23)	Percent
Visual dysfunction	23	100
Headache	17	74
Photophobia	13	57
Concentration and memory	11	48
Fatigue/low energy/drowsy	10	43
Insomnia	7	30
Nausea	7	30
Balance	7	30
Irritability/mood changes/ anxiety	7	30
Vertigo/dizzy	7	30
Neck pain	2	9

Reaction Time Methods

The primary outcome measure was CVRT and PVRT as measured by the D2 system.[4,5,8,10,18] To test CVRT (Figures 1 A–D), with both eyes open, the patients were told to hold down a peripherally located button with one hand and look directly at the button to be lit up.[8] The button that would light up was located directly in front of the patient's central field of vision. When the central light was lit up, the patient would release the first button and press the centrally lit button, which would then extinguish the light. The light turning off indicated that the button had been successfully pressed. The time from when the light turned on to the time when the light turned off was recorded as the CVRT. This was repeated to test the right and left hands, once per hand. The average CVRT was calculated for each patient.

To test PVRT (Figures 2 A–D), subjects were first binocularly fixated on a light centrally located on the D2 board. Next, a light would light up at an angle of 45 degree in the peripheral field of vision of the patient. Once lit up, the patient was instructed to press the lit button as quickly as possible. When the button was pressed successfully, the light was extinguished. The time from when the light turned on to the time when the light turned off was recorded as the PVRT. With binocular vision, both the left and right visual fields were tested independent of each other. The average PVRT was calculated for each patient.

Statistics

T test calculations were performed with Microsoft Excel. A 2-tailed *t* test for unpaired groups of equal variance was used for calculations between the postconcussion visual dysfunction group and the control group. Results were considered statistically significant with a P value of <0.05.

RESULTS

The mean Central Vision Reaction Time for the postconcussion group was 0.357 ± 0.118 seconds, which was 0.063 seconds ($P = 0.000$) longer than the Central Vision Reaction Time for the control group of 0.294 ± 0.044 seconds. The mean PVRT for the postconcussion group was 0.477 ± 0.146 seconds, which was 0.137 seconds ($P = 0.000$) longer than the PVRT for the control group of 0.340 ± 0.049 seconds. Within the control group, the difference between the CVRT and PVRT was 0.046 seconds, which represented a 15.6% increase in the relative reaction time (%ΔT) from central to PVRT. Within the postconcussion group, the difference between CVRT and PVRT was 0.120 seconds, which represented a 33.6% increase in the %ΔT from central to PVRT. The increase in %ΔT from 15.6% in the control group to 33.6% in the postconcussion group was statistically significant ($P = 0.000$).

DISCUSSION

Visual dysfunction has been reported in patients after a concussion.[2–8,10,15,18] Visual dysfunction has further been

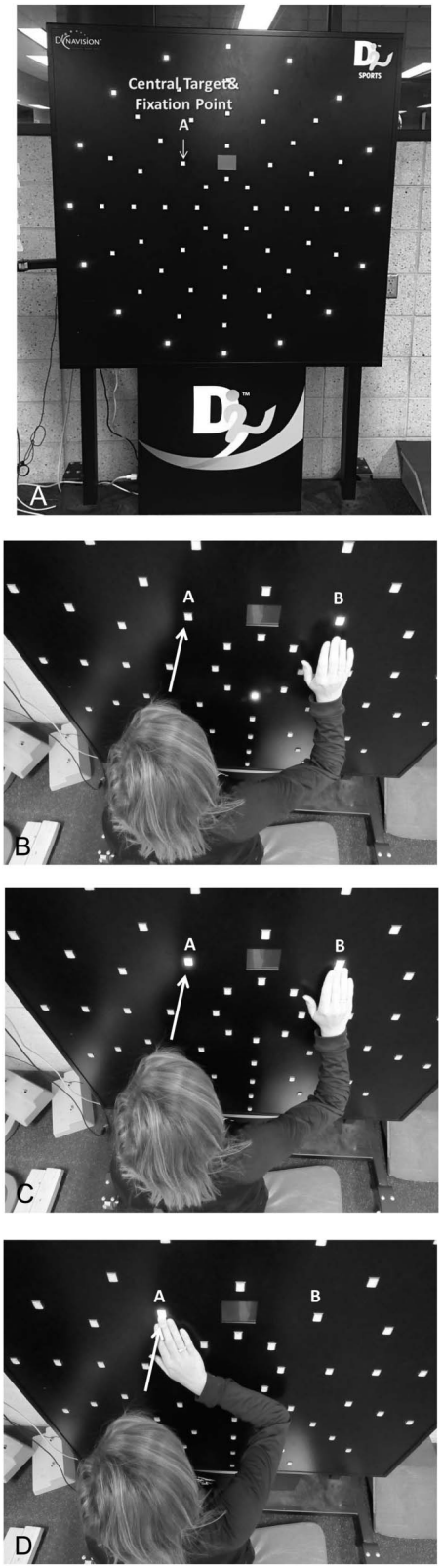

FIGURE 1. A–D, Central vision reaction time. A, Button A is lit button A on the Dynavision board. It is used for the central target to be hit. The subject's eyes stay fixed on button A for the test. B, The patient holds down button B and looks directly at button A standing 14 inches from the board (visual focus indicated by white arrow). C, Button A will light up. D, The patient will use the hand holding button B to hit button A. When button A is pressed the light is extinguished. The time from button A turning on and button B no longer being pressed is the central reaction time; typically a mean of 5 repetitions is reported. The white arrow represents the direction of gaze for the person being tested.

associated with patients feeling 1 step behind themselves,[3] in other words, feeling slower than baseline in terms of reaction time. The aim of this study was to determine whether reaction times were prolonged in patients with postconcussion visual dysfunction.

The diagnosis of concussion remains a challenge because it largely is dependent on patient self-report.[2,19–21] This becomes even more challenging in patients who have premorbid symptoms of concussion such as headache, fatigue, and insomnia, which are ever present among the general population. Furthermore, it is difficult to objectively track the aforementioned symptoms over time because of their subjective nature. Based on our data, CVRT, PVRT, and subsequent %ΔT may provide objective data markers that are independent of the subjective symptoms reported by the patient.[6,22,23]

Both CVRT and PVRT were significantly prolonged in patients with postconcussion visual dysfunction compared with the control group. This implies that evaluating CVRT and PVRT may be useful in aiding in the diagnosis of patients with postconcussion visual dysfunction. Furthermore, if individualized baseline patient data or normalized, age-matched data were available, CVRT and PVRT might be even more useful in making this diagnosis. It is important to note that there was a disproportionate prolongation in the PVRT in the injured individuals compared with the control group. This indicates that PVRT may be a more sensitive indicator than CVRT of patients with postconcussion visual dysfunction, as suggested by previous research.[22]

The prolongation of PVRT relative to CVRT (%ΔT) may be of additional benefit when assessing postconcussion visual dysfunction. It is possible for a patient simply to have slowed reaction times at baseline when compared with the general population. In such a case, prolonged central and/or PVRT may not indicate concussion. Our results suggest that healthy individuals with no history of concussion should not have excessive increase of %ΔT. As such, an increase in a patient's %ΔT, even with slow baseline reaction times, may indicate concussion symptoms. The converse of this may also be true, in that, a patient may have inordinately fast reaction times when compared with the general population. In this case, simply looking at either the central or PVRTs, which may be prolonged for the patient, may still fall within the age-matched population normative values despite the patient sustaining a concussion. Again in this case, an increase in %ΔT may be indicative of pathology. Because of the prolonged reaction time with a preference for PVRT, evaluating both central and PVRTs and comparing the difference between the 2 may allow for diagnosis in the absence of baseline patient data.

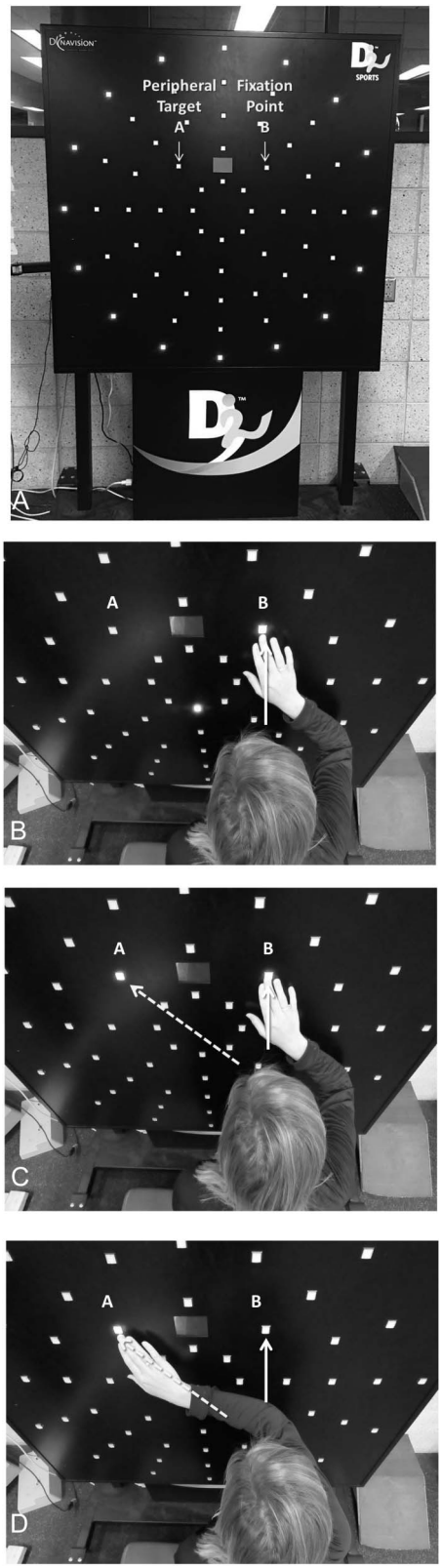

FIGURE 2. A–D, Peripheral vision reaction time. A, Button B is lit on the Dynavision board and is the button used for the peripheral reaction time. The subject fixes their eyes on button B for the test. Button A is the button to be hit when it lights up. B, The patient looks at button B standing 14 inches from the board. C, Button A approximately 45 degree in the peripheral visual field (indicated by yellow dashed arrow) will light. D, When button A lights up, the patient presses button A with the hand that had been holding button B. The time from button A turning on and button B no longer being pressed is the peripheral reaction time. The white arrow represents the direction of gaze for the person being tested.

The idea of using a patient's own anatomy to provide real time reference is not new. A common, validated, example of this is comparison nerve conduction studies in the ipsilateral and/or contralateral limb in the diagnosis of median mononeuropathy at the wrist.[23] These nerve conduction studies rely on the relative symmetric response of nerve action potentials within the same patient in the absence of pathology. Any prolongation or asymmetry of nerve action potentials is used as a clue to guide the diagnostician toward the correct diagnosis. We believe a similar philosophy could be applied to the reaction times observed in the postconcussion population.

Prolonged reaction times can negatively affect patient safety.[24] Athletes have to protect themselves on the field of play as do the general public who are engaged in activities such as driving. Central and PVRTs may have implications in determining when patients may be safe to return to play and/or return to normal activities of daily living. Similar to how CVRT and PVRT may aid the diagnosis of concussion symptoms by circumventing patient subjectivity, they may be used to objectively track a patient's visual field dysfunction over time. Although not followed in this study, it is hypothesized that the CVRT and PVRT will improve over time, indicating improvement in postconcussion symptoms. This again would provide an objective marker that is independent of patients who may be incentivized to return to play or work before the resolution of their symptoms. Future studies to assess the temporal changes associated with CVRT and PVRT are needed to substantiate this hypothesis.

There are several limitations of our study. First, our postconcussion group only included patients with visual symptoms after a concussion, rather than any patients who had sustained a concussion. This limits the broader diagnostic implications of our results, specifically, the generalizability to all patients who have sustained a concussion. Second, our sample size of 23 patients, though a large enough sample size to provide statistically significant results, is too small to determine age-matched, normalized values that can then be applied to the general population. Third, our study did not follow patients over time with serial CVRT and PVRT analysis. This limits our ability to comment on the temporal changes that occur in CVRT and PVRT for patients who have sustained a concussion. Finally, this study used a 45 degree off-center angle for peripheral vision testing; other angles were not investigated. The PVRT prolongation and %ΔT may have been more severe if a larger off-center angle was used.

Future studies are needed to better determine the role of CVRT and PVRT in concussion patients without visual dysfunction. This will help determine whether reaction times are valuable in the assessment of all patients who have

sustained a concussion, or simply the subset of patients with postconcussion visual dysfunction. A large scale study of normal subjects is needed to determine age-matched, normalized data. These data, we believe, may be applied in the absence of baseline data to potentially aid in the diagnosis of concussion. Also, a longitudinal study is needed to follow concussion patient's reaction times while collecting information about specific subjective symptoms over time. The above studies should investigate the optimum angle for assessing PVRT.

In conclusion, CVRT and PVRT are both prolonged in patients with postconcussion visual dysfunction with PVRT being disproportionately prolonged when compared with a group of healthy volunteers. The %ΔT from CVRT and PVRT was also increased in patients with postconcussion visual dysfunction when compared with a group of healthy volunteers.

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