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Inter-hemispheric wave propagation failures in traumatic brain injury are indicative of callosal damage

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ABSTRACT

Approximately 3.2–5.3 million Americans live with the consequences of a traumatic brain injury (TBI), making TBI one of the most common causes of disability in the world. Visual deficits often accompany TBI but physiological and anatomical evidence for injury in mild TBI is lacking. Axons traversing the corpus callosum are particularly vulnerable to TBI. Hemifield representations of early visual areas are linked by bundles of fibers that together cross the corpus callosum while maintaining their topographic relations. Given the increased vulnerability of the long visual axons traversing the corpus callosum, we hypothesized that inter-hemispheric transmission for vision will be impaired following mild TBI. Using the travelling wave paradigm (Wilson, Blake, & Lee 2001), we measured inter-hemispheric transmission in terms of both speed and propagation failures in 14 mild TBI patients and 14 age-matched controls. We found that relative to intra-hemispheric waves, inter-hemispheric waves were faster and that the inter-hemispheric propagation failures were more common in TBI patients. Furthermore, the transmission failures were topographically distributed, with a bias towards greater failures for transmission across the upper visual field. We discuss the results in terms of increased local inhibition and topographically-selective axonal injury in mild TBI.

1. Introduction

Approximately 3.2–5.3 million Americans live with the consequences of a TBI making it one of the foremost causes of disability in the USA (Coronado et al., 2011; Corrigan, Selassie, & Orman, 2010). Visual deficits are one of the most common complaints after TBI (Greenwald, Kapoor, & Singh, 2012; Kapoor & Ciuffreda, 2002). TBI results from an insult to the brain from an external mechanical force and is often associated with perceptual or cognitive impairment. The sudden acceleration and deceleration that occur during a concussion are thought to stress, stretch and tear connecting axons (Meythaler et al., 2001). The effects of axonal injury in TBI on visual deficits are poorly understood, despite our vast knowledge of cortico-cortical connectivity of the visual system.

The inter-hemispheric pathways connecting the primary and extrastriate visual cortices are important for a coherent perception of the visual scene. Integration across the visual field is essential for tasks such as visuomotor coordination (Peru et al., 2003) and reading (Brysbaert, 1994). Performance on such tasks is often compromised following TBI (Caeyenberghs et al., 2011; Kapoor & Ciuffreda, 2002). Understanding the causes of visual impairment in TBI is therefore critical to the development of novel therapies that are not only compensatory, but also restorative (Ciuffreda et al., 2008; Schlageter et al., 1993; Schuett & Zihl, 2013).

The callosal connections of the early visual areas are amongst the longest in the human brain—they span from the occipital pole in one hemisphere to the other—but it is unclear if they are implicated in TBI-associated visual deficits. Callosal connections are particularly susceptible to diffuse axonal injury (Benavidez et al., 1999; Mendelsohn et al., 1992) and their injury has been linked to a variety of neurocognitive deficits. For example, Caeyenberghs et al. (2011) report that TBI-induced decrease of fractional anisotropy in the corpus callosum measured by diffusion tensor imaging (DTI) was related to impaired bimanual coordination in young adults. Another recent study showed that reduced fractional anisotropy and higher radial diffusivity of the corpus callosum was related to poorer verbal and visuospatial working

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memory in children (Treble et al., 2013). Finally, TBI-induced changes to the corpus callosum were associated with abnormal performance in verbal dichotic listening and tachistoscopic identification of verbal material (Benavidez et al., 1999). Thus, TBI does appear to cause injury to the corpus callosum.

Given the role of callosal connections in linking visual field representations in early visual cortex, we sought to measure two components of inter-hemispheric transfer in vision after mild TBI—the speed of transfer and the success of transmission. To make both measurements, we employed the travelling wave paradigm of Wilson, Blake, and Lee (2001). The paradigm involves dichoptic presentation of two different, and therefore rivalrous, ring stimuli to the two eyes. The switch of dominance between the two monocular retinal images does not occur at once but it is rather accompanied by systematic transition along the ring in the form of a "travelling wave" sweeping across the visual field ((Wilson, Blake, & Lee, 2001); Fig. 1).

The onset of travelling waves can be controlled by a stimulus trigger which allows us to quantify the speed of the travelling wave—the rate at which the wave sweeps from the trigger to the arrival point. When the trigger and target are in different hemifields, the wave of neural activity must then traverse the corpus callosum. Inter-hemispheric waves tend to be slower, likely due to transcallosal transfer (Genç et al., 2011b). In the absence of TBI, the speed of an inter-hemispheric wave is related to the fractional anisotropy of the V1–V1 transcallosal projections as measured by DTI—higher fractional anisotropy (FA) was associated with slower inter-hemispheric speeds. It is difficult to determine

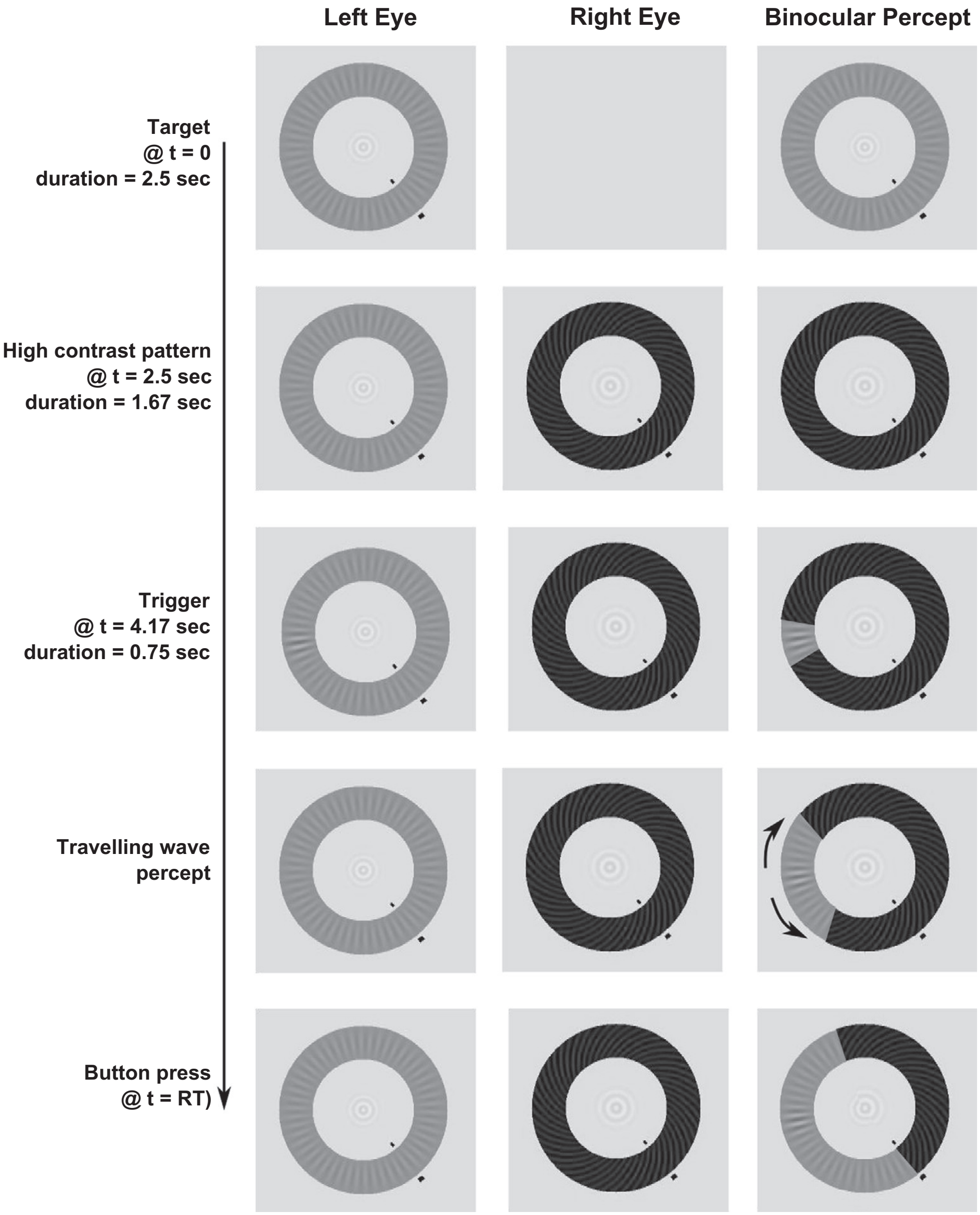

Fig. 1. Stimuli presentation. This example depicts one of the eight possible conditions (see Section 2). The trial begins with the presentation of the target pattern to the left eye and no pattern in the right. After 2.5 s, the high contrast spiral pattern is presented to the right eye and perceptually suppresses the target pattern. The trigger presented in the suppressed eye 1.67 s later for 0.75 s elicits the travelling wave percept in both directions. Here, the trigger is presented to the left eye at 110° of polar angle clockwise with respect to the vertical meridian. The shortest path to the arrival point is 120° of polar angle away clockwise. Participant pressed the space bar to report the wave crossing the nonius lines.