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REGULAR ARTICLE

Enhancing visual performance in individuals with cortical visual impairment (homonymous hemianopsia): Tapping into blindsight

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Abstract Homonymous hemianopsia is a type of cortical blindness in which vision is lost completely or partially in the left half or the right half of the field of vision. It is prevalent in approximately 12% of traumatic brain injury and 35% of strokes. Patients often experience difficulty with activities such as ambulating, eating, reading, and driving. Due to the high prevalence of homonymous hemianopsia and its associated difficulties, it is imperative to find methods for visual rehabilitation in this condition. Traditional methods such as prism glasses can cause visual confusion and result in patient noncompliance. There is a large unmet medical need for improving this condition. In this article, we propose that modifying visual stimuli to activate non-cortical areas of visual processing, such as lateral geniculate nucleus and superior colliculus, may result in increased visual awareness. Presenting high contrast and low spatial frequency visual stimuli can increase visual detection in patients with cortical blindness, a phenomenon known as blindsight. Augmented virtual reality goggles have the potential to alter real-time visual input to high contrast and low spatial frequency images, possibly improving visual detection in the blind hemifield and providing an alternative therapy for homonymous hemianopsia.

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Introduction

Cortical visual impairment comprises a significant component of strokes and traumatic brain injury. Cortical visual impairment includes homonymous hemianopsia, in which vision is lost completely or partially in the left half or the right half of the field of vision. Homonymous hemianopsia is prevalent in approximately 12% of traumatic brain injury and 35% of strokes [1–3]. Individuals with this vision loss usually have difficulties with activities of daily living such as ambulating, eating, reading, and driving [4,5]. Due to the high prevalence of homonymous hemianopsia and its associated difficulties, it is imperative to find methods for visual rehabilitation in this condition. Traditional methods of visual rehabilitation for homonymous hemianopsia include fitting spectacles with prisms to shift the visual field from the blind hemifield to the intact visual field. This is accomplished by placing the base of the prism in the blind hemifield, which shifts the image toward the apex of the prism into the intact hemifield. Many patients discontinue treatment with prisms because the prisms may induce visual confusion and double vision [1–4]. Another technique used is to train individuals with hemianopsia to make quick eye movements in the direction of the blind hemifield, though there is not much evidence supporting efficacy [6]. Although these methods may provide some compensation for the visual field loss, they do not restore the impaired visual field. Accordingly, other methods of improving vision are needed.

Individuals with homonymous hemianopsia do not consciously see vision in the blind hemifield. However, there is evidence of a ‘blindsight’ phenomenon, whereby some affected individuals can detect objects in their blind visual field, albeit without conscious awareness of being able to see the object. Functional magnetic resonance imaging (fMRI) studies have indicated that visual processing occurs in other parts of the brain, such as the lateral geniculate nucleus (LGN) and superior colliculus (SC) (Fig. 1). Visual processing in these regions provides the neural network that enables patients with blindsight to see [7–11]. Blindsight has been manipulated in some individuals to enhance visual awareness. Sahraie et al. studied a patient with homonymous hemianopsia and well-documented blindsight over a long period of time [7]. The patient reported increased awareness of visual stimuli in his blind visual field when the stimulus was presented with high contrast and low spatial frequency. Spatial frequency refers

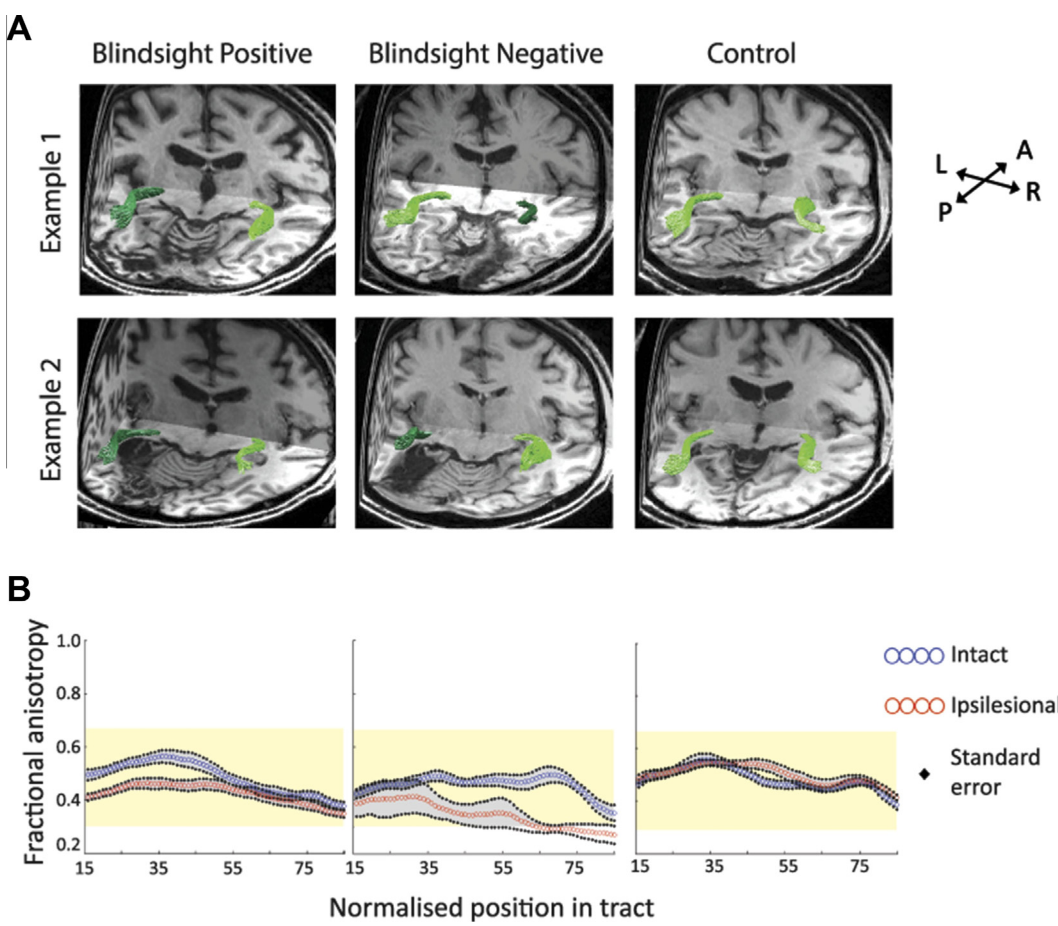

Figure 1 3-D representation of tracts overlaid on T1-weighted fMRI images between the lateral geniculate nucleus (LGN) and human motion complex (hMT+), adapted from Ajina and colleagues (eLife. 2015;4:e08935. doi: 10.7554/eLife.08935) [26]. (A) Dark green tracts are in the ipsilesional hemisphere, light green tracts are in the contralesional hemisphere and in controls. (B) Fractional anisotropy, reflecting neuronal damage, demonstrates increased impaired tissue microstructure in the ipsilesional tract in blindsight negative patients as compared with blindsight positive patients and controls.

to the level of detail in an image appearing within a degree of the visual field. Temporal frequency, the number of times a stimulus is flashed within a second, also modulates detection. Multiple studies have shown that within a temporal frequency range of 5–20 Hz (cycles/s), detection of visual stimuli in a forced-choice test is significantly better than chance [7–11]. The time of stimulus onset also affects the rate of detection. Patients with parietal lobe injury often cannot detect a visual stimulus in the neglected hemifield when it is presented simultaneously in the intact hemifield, but can detect the stimulus when it is presented by itself in the neglected hemifield only, a phenomenon known as visual extinction [12,13]. It is thought that visual extinction reflects an attentional deficit as opposed to primarily a sensory deficit, although this remains an area of active research [14]. Despite that visual extinction is primarily studied in patients with hemi-neglect, patients with hemianopsia also can have hemi-neglect from injury to both the occipital and parietal lobes [15]. Therefore, the relevant visual variables for increasing visual detection in hemianopsia are stimuli contrast, spatial frequency, temporal frequency and stimulus onset asynchrony.

Hypothesis

We propose that real-time visual input can be altered to have high contrast, low spatial frequency, low temporal frequency, and appropriate stimulus onset asynchrony using augmented virtual reality goggles (Fig. 2). Augmented virtual reality goggles, which overlay real-world input with a virtual display, have been developed in the past few years. Head-mounted displays such as such as the Cast AR (http://technicalillusions.com/) or Daqri Smart Helmet (http://hardware.daqri.com/smarthelmet/) may offer potential solutions to modify visual stimuli in such ways as to allow people with hemianopsia to improve visual detection. This new technology which has been marketed toward business and gaming applications may be an ideal method for visual rehabilitation for individuals with homonymous hemianopsia. Weiskrantz's group at Oxford University [8], Huxlin's group at the University of Rochester [10], and others have studied visual detection with Gabor patches and checkerboard reversal in patients with homonymous hemianopsia. To our knowledge, no one has published information on the detection rate of real time video images, the logical next steps. We expect the image detected in the blind hemifield will be rudimentary, but this would be the first time that a true extension of vision in the blind hemifield will be documented using blindsight (Fig. 3).

Evaluation of the hypothesis

The following research directions are recommended for the evaluation of our hypothesis:

(1) Baseline studies of people affected by homonymous hemianopsia to assess the best spatial frequency, temporal frequency, and stimulus onset asynchrony delay required for each individual for real visual stimuli (Fig. 1). If necessary, this could be performed by displaying video clips on a computer screen before using augmented virtual reality goggles. Previously, temporal frequencies of pattern-reversal at 10 Hz frequency have been documented to produce the highest rates of detection in hemianopsia [16–18]. A spatial frequency of 1 cycle per degree for both images has been shown to elicit the highest rates of detection among homonymous

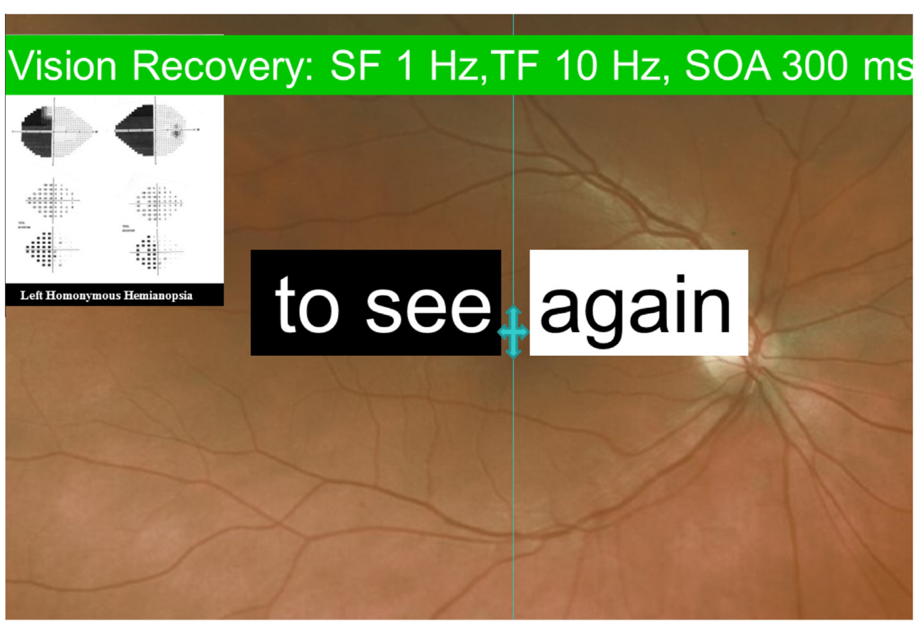

Figure 2 Testing of a subject with left homonymous hemianopsia visual field defect from right occipital stroke with augmented visual information – presented at a spatial frequency of 1 cycle/degree (1 Hz), temporal frequency of 10 cycles/degree (10 Hz), and stimulus onset asynchrony of 300 ms – presented temporal of the fovea in the right eye (and correspondingly, nasal of the fovea in the left eye), and unfiltered visual information presented nasal of the fovea in the right eye (and correspondingly, temporal of the fovea in the left eye).

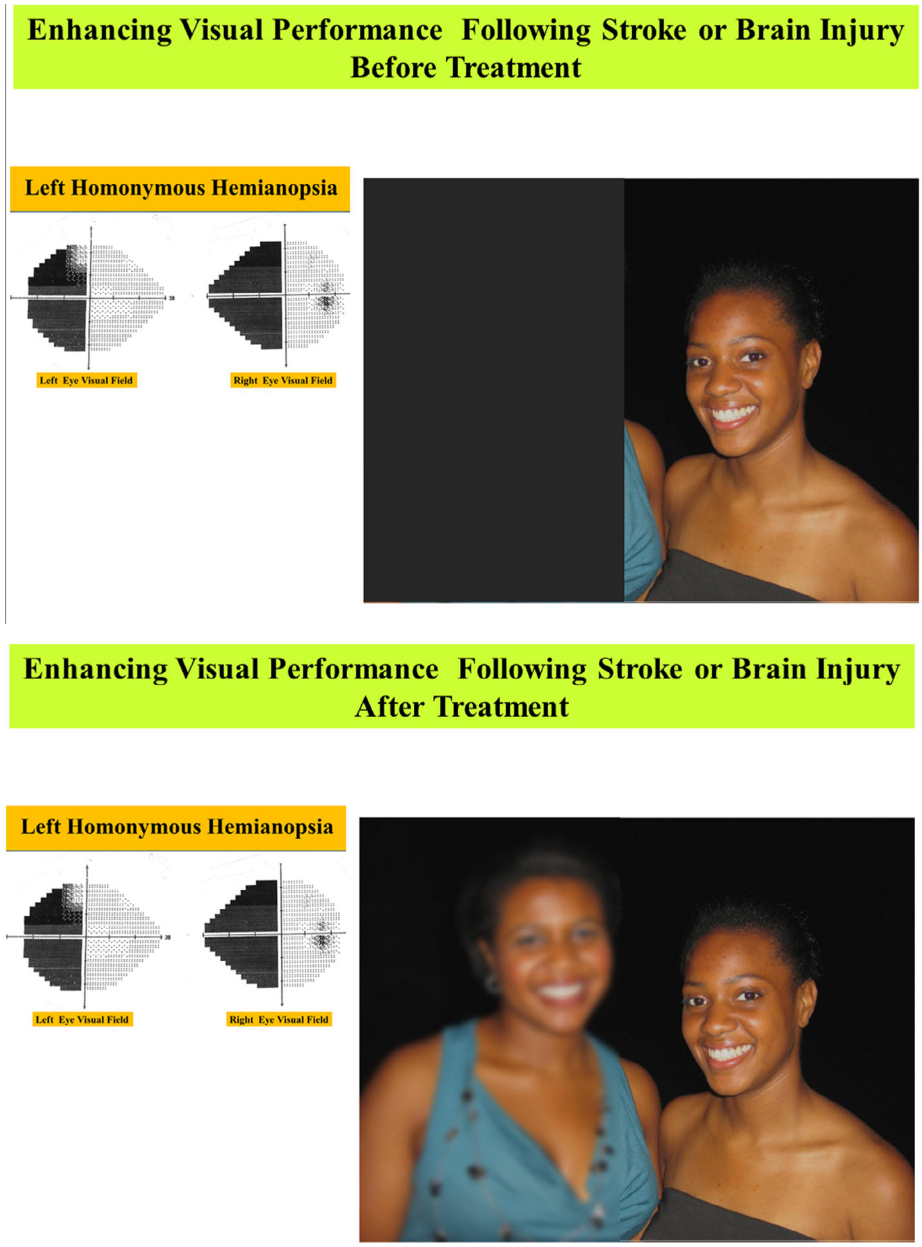

Figure 3 Visual improvement of a subject with left homonymous hemianopsia visual field defect from right occipital traumatic brain injury: (A) before treatment; (B) after treatment using augmented reality goggles.

hemianopsia subjects [8]. An optimal stimulus onset asynchrony (SOA) is likely between 50 ms and 300 ms, per previous hemi-neglect and hemianopsia patients [13,19].

(2) fMRI imaging of non-cortical visual processing areas during visual detection tasks can confirm increased activation to specific visual parameters.

(3) Clinical comparative effectiveness research of daily activities performed by patients with homonymous hemianopsia using augmented virtual reality goggles displaying altered visual parameters compared to patients without goggles.

Discussion

Several groups have studied visual detection with Gabor patches and checkerboard reversal in patients with homonymous hemianopsia [6–10,13]. In patients with blindsight, detection rates were highest with spatial frequencies ranging from 1 to 3.5 cycles/degree [6–10]. Multiple studies have shown that within a temporal frequency range of 5–20 Hz (cycles/s), detection of visual stimuli in a forced-choice test is significantly better than chance [9,10]. Detection drastically drops off outside of this "window of temporal sensitivity". Additionally, studies have shown stimuli with motion have a higher detection rate than static stimuli (Riddoch phenomenon).

One proposed mechanism is that this combination of spatial frequency, temporal frequency, and contrast activate the magnocellular ganglion cells (M-cells) of the retina which project to the lateral geniculate nucleus (LGN) and superior colliculus (SC), structures which have been implicated in blindsight. Interestingly, it is thought that the magnocellular cells are also targeted by the continuous flash suppression technique, whereby a continuously moving stimulus is presented to one eye while a static image is presented to the other eye, causing the static image to disappear from visual awareness [20]. Kleiser and colleagues have reported similar findings involving three patients with homonymous hemianopsia who were able to recognize a high-contrast reversing checkerboard in their blind field [21]. Likewise, Johnson has shown that the ability of an individual to appreciate binocular fusion as with the near Worth 4-dot test, can be altered by adjusting the time delay and/or amplitude of the light stimulus presented to one eye relative to the other eye using a neutral density filter [22]. In monkeys with a primary visual cortex (V1) lesion causing a scotoma, saccadic eye movements indicated the monkeys were able to see high contrast rotating checkerboards but not low contrast images. When researchers lesioned these monkey's LGN, the monkeys were not able to respond to any visual stimuli in the scotoma area [23]. Although damage to the LGN abolished responses, the LGN may not have functioned as the site for critical processing of visual information, but more as a relay to preserved cortical areas underlying blindsight (e.g., area V5/MT for Riddoch's phenomenon). Therefore, in assessing blindsight, it is important to determine which area of the brain has been damaged as blindsight may not exist if other key visual-processing areas are injured.

The mechanism of increased visual detection with stimulus onset asynchrony is not well understood. Visual extinction has been more frequently studied in patients with hemi-neglect, typically caused by damage to the parietal lobe. These patients often will detect a single stimulus presented in either hemifield on confrontation visual field test, but will not detect the contralesional stimulus when both stimuli are presented simultaneously [12]. Hemi-neglect patients also have reported the ipsilesional stimulus as appearing first, unless the contralesional stimulus has a lead time stimulus onset asynchrony of over 200 ms [13]. In hemianopsia, participants had delayed saccades to the intact visual field when a stimulus was presented simultaneously or 50 ms preceding it [24]. Similarly, primates with unilateral lesioned striate (V1) cortex demonstrated slowed reaction times to a visual stimulus in the intact field when a visual stimulus in the blind field preceded it by 100–500 ms [19]. This detection difference may reflect a delay of attention, in which the first target interferes with the attentional processing of the second target [25]. This detection difference also may reflect the amount of time it takes for a stimulus to reach consciousness threshold [25]. Visual extinction is a graded effect, meaning that subjects perform poorest with no stimulus onset asynchrony delays, intermediate with intermediate stimulus delays, and best with optimal stimulus delays [25]. Although the mechanism of visual extinction is not known, this property may still be exploited to help patients with homonymous hemianopsia.

Conclusion

Several groups have studied visual detection with Gabor patches and checkerboard reversal in patients with homonymous hemianopsia [6–10,13]. However, to our knowledge, no one has published information on the detection rate of real images and real time video to the logical next steps. Imagine augmented reality goggles adapted for patients with homonymous hemianopsia in which the right half or left half of the visual field can, in real time, be "tuned" by the patient to the optimal settings of spatial frequency, temporal frequency, contrast to allow images from the blind hemifield to be perceived. Specifically, a flickering image (20 Hz), with exaggerated contrast, and bandpass filtered to about 0.5–4 cycles/degree would be displayed to the impaired half of each eye (see Fig. 2). Enough information might be registered to aide mobility, guide hand movement or, at the least, trigger an eye movement toward the relevant objects. This approach differs radically from earlier efforts to develop prosthetic devices based on passive, optical methods. Augmented reality goggles offer the possibility of a true extension of vision in the blind hemifield for the first time (Fig. 3).

Overview box

What do we already know about the subject?

Some patients with homonymous hemianopsia experience blindsight, whereby they can detect visual stimuli by forced choice without having conscious awareness. Images that have high contrast, low spatial frequency, low temporal frequency, and asynchronous onset have the best detection.

What does your proposed theory add to the current knowledge available, and what benefits does it have?

Our theory applies what is known about blindsight to the most recent innovations in the technological industry, augmented virtual reality goggles, to create a novel therapy for patients with homonymous hemianopsia and blindsight. Currently, no proven method exists for restoring vision in homonymous hemianopsia.

Among numerous available studies, what special further study is proposed for testing the idea?

The optimal visual parameters for visual detection of video need to be tested in patients with homonymous hemianopsia. Clinical trials are recommended to evaluate if visual input modified in real-time via augmented virtual reality goggles improves visual detection in homonymous hemianopsia.

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Conflict of interest

No conflicting relationship exists for any author.

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