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An action video game for the treatment of amblyopia in children: A feasibility study

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ABSTRACT

The gold-standard treatment for childhood amblyopia remains patching or penalizing the fellow eye, resulting in an average of about a one line (0.1 logMAR) improvement in visual acuity following ≈120 h of patching in children 3–8 years old. However, compliance with patching and other treatment options is often poor. In contrast, fast-paced action video games can be highly engaging, and have been shown to yield broad-based improvements in vision and attention in adult amblyopia. Here, we pilot-tested a custom-made action video game to treat children with amblyopia. Twenty-one (n = 21) children (mean age 9.95 ± 3.14 [se]) with unilateral amblyopia (n = 12 anisometropic and n = 9 strabismic) completed 20 h of game play either monocularly, with the fellow eye patched (n = 11), or dichoptically, with reduced contrast to the fellow eye (n = 10). Participants were assessed for visual acuity (VA), stereo acuity and reading speed at baseline, and following 10 and 20 h of play. Additional exploratory analyses examined improvements after 6–10 weeks of completion of training (follow-up). Following 20 h of training, VA improved, on average, by 0.14 logMAR (≈38%) for the dichoptic group and by 0.06 logMAR (≈15%) for the monocular group. Similarly, stereoacuity improved by 0.07 log arcsec (≈17%) following dichoptic training, and by 0.06 log arcsec (≈15%) following monocular training. Across both treatment groups, 7 of the 12 individuals with anisometropic amblyopia showed improvement in stereoacuity, whereas only 1 of the 9 strabismic individuals improved. Most improvements were largely retained at follow-up. Our feasibility study therefore suggests that the action video game approach may be used as an effective adjunct treatment for amblyopia in children, achieving results similar to those of the gold-standard treatment in shorter duration.

1. Introduction

While the consequences of abnormal visual development have been known for several centuries, millions of children go undiagnosed and therefore untreated every year. Current reports put the prevalence of amblyopia at about 2.4% of the population, affecting approximately 15 million children worldwide (Wu & Hunter, 2006). As a result, these patients face the possibility of permanent monocular vision loss and a greater likelihood of complete impairment if vision to the good eye is disturbed through injury or disease (Williams & Harrad, 2006). Amblyopia can also negatively impact one's quality of life, resulting in reduced reading and fine motor skills, and may even negatively affect an individual's self-image (Choong, Lukman, Martin, & Laws, 2004; Chua & Mitchell, 2004; Horwood, Waylen, Herrick, Williams, & Wolke, 2005; O'Connor et al., 2010; O'Connor et al., 2009; Packwood, Cruz, Rychwalski, & Keech, 1999; Rahi, Cumberland, & Peckham, 2006; Webber, Wood, Gole, & Brown, 2008a, 2008b).

Amblyopia is accompanied by widespread processing deficits in a range of visual functions that cannot be solely explained by abnormalities in primary visual cortex (see Kiorpes, 2006; Levi 2006; Levi 2013 for reviews). Despite this, the standard treatment for amblyopia, refractive correction and occlusion ('patching') or penalization of the

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fellow (non-amblyopic) eye, focuses on improving visual acuity. While it is now clear that occlusion therapy can be effective, it also has some significant limitations. For one thing, patching is slow. For example, Stewart, Stephens, Fielder, Moseley, and Cooperative (2007) report that it takes approximately 170 h of patching for two lines of improvement in VA for a 4-year-old, and 236 h for a similar effect in a 6-year-old. This jumps to over 400 h for children older than 7 years of age (Fronius, Cirina, Ackermann, Kohnen, & Diehl, 2014). Moreover, covering one eye is conspicuous, and requires the child to accept reduced visual perception while the fellow eye is covered. For these reasons, compliance can be very challenging. Further, the visual function of many children often does not improve to normal levels. In fact, a substantial proportion of amblyopic children fail to achieve normal acuity even after extended periods of treatment (Birch & Stager, 2006; Birch, Stager, Berry, & Leffler, 2004; Repka et al., 2003; Repka et al., 2004; Repka et al., 2005; Rutstein et al., 2010; Stewart, Moseley, Stephens, & Fielder, 2004; Wallace et al., 2006; Woodruff, Hiscox, Thompson, & Smith, 1994). Even when vision is fully normalized, as many as 25% of patients experience a recurrence within the first year of treatment (PEDIG, 2004).

For these reasons, over the last two decades, there have been a number of attempts to develop more efficient treatments for childhood amblyopia, using perceptual learning and video game techniques (see Birch, 2013; Hess & Thompson, 2015; Levi, 2012; Levi, Knill, & Bavelier, 2015; Levi & Li, 2009 for reviews), either monocularly (with the amblyopic eye; AE) or dichoptically (with different information presented to the two eyes in order to reduce suppression and/or enhance fusion). A summary of the main studies testing such treatments in children is provided in Table 1.

An important limitation on clinical adoption of these methods for treating amblyopia in children is compliance. Laboratory-based perceptual learning is generally repetitive and tedious. As a result, several groups have recently moved toward either gamified versions of perceptual learning tasks or full-fledged video games that exploit the appeal of games developed for entertainment. However, gamified perceptual learning tasks may not have the same level of appeal and engagement as commercial action video games. Unlike lab-based gamified perceptual learning, the video game industry is a multi-billion-dollar segment of the entertainment media, and designers face intense competition to create rich, immersive and engaging environments. The result is a more compelling experience that is more enjoyable and overcomes much of the tediousness experienced in perceptual learning regimes. Importantly, it is now well established that in normal adults, action video games enhance various aspects of visual perception, above and beyond other video game genres such as social simulation games or Tetris (see for example, Green, Li, & Bavelier, 2010).

While action video games were initially defined as first- and third-person shooter video games by the video game industry, we (and others) now consider action video games as those that combine a number of features or game mechanics that facilitate brain plasticity and learning. Among these mechanics, are the need to execute actions under time constraints, a high load on divided attention, the appropriate switch between focused and divided attention as task demands change, the requirement to plan at many different time scales, from milliseconds to hours, and the use of variable value and time reward schedules, to cite a few (Green et al., 2010). Thus, video games do not have to have violent content in order to be considered as action games.

Commercial action video games are compelling and highly engaging. These games often include targets and enemies that move into and across the visual field. To succeed, players must be able to both distribute their attention widely and focus to the most relevant areas of the screen, and make spatial decisions under time pressure by aligning a cross hair or viewing scope to the target of interest. Once a decision has been made, the player receives immediate feedback in the form of points or negative consequences. Like perceptual learning, the level of game difficulty also increases as the players improve.

Action video games also trigger arousal and provide nuanced feedback on performance, which may be critical for efficient learning (Bavelier, Green, Pouget, & Schrater, 2012). Most importantly, however, action video games have a variety of salient content over the entire screen, leading to behavioral enhancements that are broader than the retinotopic and task-specific changes that are often observed in PL (but see Xiao et al., 2008; Zhang, Cong, Klein, Levi, & Yu, 2014). Playing action video games results in significant improvements in a broad range of visual functions, from low-level to high level in normal adults (Green & Bavelier, 2007; Li, Polat, Makous, & Bavelier, 2009; Li, Polat, Scalzo, & Bavelier, 2010).

In contrast to neurotypical adults, adults with amblyopia show improvements in vision after playing commercial video games – either action (Medal of Honor) or non-action (Sim City) video games (Li, Ngo, & Levi, 2015; Li, Ngo, Nguyen, & Levi, 2011) monocularly, with the fellow eye patched. For example, Li et al. (2011, 2015) showed that playing video games monocularly with the AE resulted in a broad range of improvements (visual acuity, stereoacuity, positional acuity, and spatial and temporal attention) in adults with amblyopia. However, an important principle of learning is that task difficulty should be adapted to the learner's capacity. From this point of view, commercially available action video games designed by the industry for experienced gamers with normal vision may not be ideal, but should be modified to include easier levels adapted to the specific challenge of playing with degraded vision. Scaffolding the learning experience for the patient is a key design principle that should not be overlooked.

A number of recent studies have used dichoptic games, aimed at improving stereovision by reducing suppression and/or enhancing fusion for both adults (Hess & Thompson, 2015; Vedamurthy et al., 2015) and children (Kelly et al., 2016). For example, in a recent study, Kelly et al. (2016) had children play DigRush - a game in which children manipulate miners and their surroundings to dig for gold, while avoiding obstacles. However, to date there have not been studies using action video games (either monocular or dichoptic) with amblyopic children.

The aim of the current study was to test the feasibility and initial efficacy of using a customized action video game with a population of amblyopic children (age 7–17). While several groups have recently conducted studies with similar goals using both non-action games and movie viewing (see Table 1), they all cite motivation and compliance as challenging factors that may be limiting their results. Importantly, we compared the dichoptic video game to an identical video game played monocularly, with the fellow eye patched. Unlike the "sham" treatment where the content to the two eyes is reversed (i.e., high contrast to the fellow eye and low contrast to the weak eye, ensuring that the AE will be suppressed during play – e.g. Birch et al., 2015; Li et al., 2014), this control condition incorporates the traditional gold standard treatment. Our 'patching-while-playing' control should help provide further insight into whether dichoptic action video game play yields greater improvement than monocular action video game play. Previous studies in children have been equivocal, with some reporting greater improvement with dichoptic training (e.g. Kelly et al., 2016) and others reporting little or no advantage to the effects of dichoptic training (Tetris) over patching (e.g. Holmes et al., 2016).

2. Methods

2.1. Study participants and ethics statement

The study took place in research laboratories, at University of