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Improving Adult Amblyopic Vision with Stereoscopic 3D Video Games

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Based on recent observations that brief exposures to very large disparities can restore stereopsis[1], we explored how adults with amblyopia respond to playing immersive video games in a three-dimensional (3D) stereoscopic environment containing disparities larger than generally encountered in natural scenes[2].

The amblyopic brain relies primarily on signals from the dominant eye and suppresses signals from the weaker eye. To remove this obstacle to binocular vision, participants wore a Bangerter filter over the dominant eye in order to reduce its crowded visual acuity by logMAR 0.2 (two lines) worse than that of the amblyopic eye, while preserving stereopsis at low and medium spatial frequencies[3]. For strabismic participants, the misalignment of the two eyes was fully corrected optically using loose prism trial lenses over the deviated eye. To ensure proper eye alignment, the prismatic prescription was refined, using the cover test and worth 4-dot test, for the gaming distance and the minimum amount of prism needed for fusion was prescribed. Note that our strabismic participants wore prisms only during gaming and stereoacuity assessment sessions. Details of the experimental procedures can be found online as supplemental materials.

First, we evaluated whether this binocular approach, in combination with 3D video game play, improved visual acuity (VA) in the amblyopic eye. Twenty-one adults with amblyopia (Table S1; aged 19–79 years; strabismic and non-strabismic; VA range, 20/20–20/160)

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HUMAN SUBJECTS: The study was approved by the University Committee for the Protection of Human Subjects (CPHS Protocol ID: 2010-08-1985), and was conducted according to the principles expressed in the Declaration of Helsinki. Informed consent was obtained from each participant.

Author Contributions:
Conception and design: Li
Data collection: Li, Tran, Bui, Antonucci, Ngo
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played an off-the-shelf 3D first-person shooter video game, while wearing a Bangerter filter over the dominant eye and prism correction if required, for 40 hours over 4 to 6 weeks (2 hours each session, 5 to 7 sessions a week).

Over the course of video game play, participants showed a rapid improvement in visual acuity of the amblyopic eye, on average logMAR 0.11 (Fig 1A, plotted in terms of mean percentage improvement in MAR, 21%) for both crowded (cVA; solid circles; 2-way RANOVA: df=4, F=31.83, p<0.001) and isolated visual acuity (iVA; open circles; 2-way RANOVA: df=4, F=26.48, p<0.001). The exponential time constant was 17 hours for both crowded and isolated visual acuities (solid and dashed lines, respectively).

Individual visual acuity data before and after the video game intervention are displayed in Figure 1B. There was no significant difference in percentage improvement between non-strabismic and strabismic participants (cVA: 2-way RANOVA: df=1, F=0.14, p=0.72; iVA: 2-way RANOVA: df=1, F=0.04, p=0.84).

To examine how 3D video game experience influences depth perception, we also measured stereoacuity using a new test we recently developed based on Gabor features (Fig 1C, lower-right inset)[3]. We found that 3D video game experience resulted in recovery of stereo vision in both anisometropic and strabismic amblyopes. The upper-left inset illustrates the stereoacuity versus spatial frequency curves obtained from a participant with the most severe anisometropic amblyopia in this study (Table S1, MBL; VA 20/80). While stereoacuity for high spatial frequencies (fine stereopsis) was severely impacted, all our amblyopic participants presented with some stereopsis for low spatial frequencies (coarse stereopsis). For example, participant MBL was able to achieve stereopsis for a range of spatial frequencies up to 5 cpd (pre, open symbols) and no measurable stereopsis was obtained for higher spatial frequencies. Upon completion of the video game sessions, the entire stereoacuity function shifted down (post, solid symbols), meaning improved stereoacuity for the range of spatial frequencies tested. Note that in addition to sensitivity, the cut-off frequency shifted toward higher frequencies allowing processing of stereopsis at finer spatial scales (a factor of 3 in this case, 5 cpd at baseline versus 15 cpd following training.

Individual stereoacuity data are displayed in Figure 1C. We observed a significant improvement in stereoacuity after 3D video game play (2-way RANOVA: V1–V2, df=1, F=10.02, p=0.01). The mean improvement in stereoacuity was 34% across different spatial frequency settings (Fig 1D, black solid line). Interestingly, in many cases, participants regained stereopsis for higher spatial frequencies to which they were previously “stereo-blind” at the baseline visit. Since no measurable stereoacuity data could be obtained for those frequency settings, their baseline data are arbitrarily set at the largest disparity tested (open symbols in Fig 1C). Those data points were not used in the calculation of mean improvement; including them increases the improvement to 39% (gray dashed line). There was no significant difference in percentage improvement among different spatial frequencies (2-way RANOVA: df=3, F=0.39, p=0.76), or between non-strabismic and strabismic participants (2-way RANOVA: df=1, F=0.35, p=0.56). The inset figure shows the proportion (or number, n) of participants with measurable stereopsis for different spatial frequencies before and after the video game intervention (dashed and solid lines, respectively). The shadow area represents those participants who regained stereopsis for higher frequencies.

Here we show that playing immersive 3D video games might have potential therapeutic value in the recovery of reduced stereopsis in amblyopia, and possibly other binocular vision anomalies. In attempting to push the brain to use the amblyopic eye while allowing binocular viewing, we adopted a filtering approach to compensate for the acuity loss in the affected eye. We chose to blur the stronger eye slightly relative to the amblyopic eye. At the commencement of the experiments, we were uncertain whether that this approach would be useful for improving amblyopic vision. Our present findings contribute to establishing a new binocular protocol for treatment of amblyopia. Importantly, unlike monocular and dichoptic video games[4], stereoscopic 3D video games might have a benefit for the recovery of stereo vision in both strabismic and anisometropic amblyopia.

Since our participants played 3D video games with the fellow stronger eye blurred, any vision enhancement could have been the result of wearing a blurring diffuser alone, and also a prism lens for strabismic participants. An important limitation of our study is the absence of a large placebo group for comparison as in our previous study[5]. We are currently expanding on-going control experiments to address this important issue and also characterizing the dose-response relationship of this new binocular approach. Randomized placebo-controlled studies, with a larger sample size, are needed before applying this new binocular technique in clinical situations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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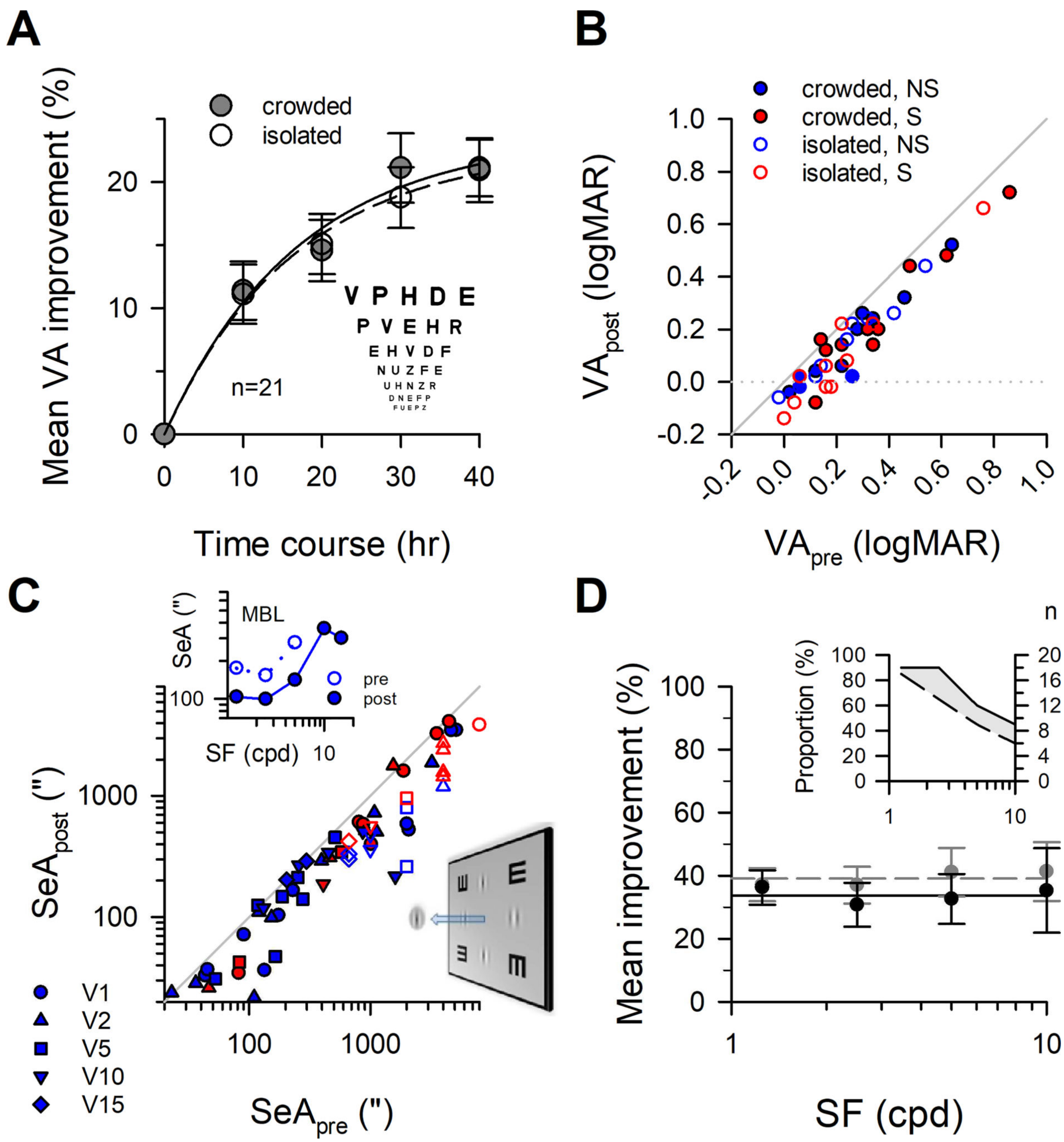

Figure 1.

Visual acuity and stereoacuity. **A**, Improved visual acuity with 3D video game experience. Solid symbols, crowded visual acuity. Open symbols, isolated visual acuity. Error bars, one standard error of the mean. **B**, Visual acuity after 40 hours of 3D video game play (VA_{post}) as a function of baseline visual acuity (VA_{pre}). Dotted-line, 20/20 visual acuity. Blue symbols, non-strabismic participants. Red symbols, strabismic participants. **C**, Improved stereoacuity (SeA) with 3D video game experience. For those previously stereo-blind participants, who had no measurable stereoacuity for a given spatial frequency stimulus, their baseline data are arbitrarily set at the largest disparity tested (open symbols). Note that the data for V15 were not included in the statistical analyses. Blue symbols, non-strabismic participants. Red symbols, strabismic participants. Upper-left inset, the stereoacuity versus spatial frequency (SF) function obtained from a participant (MBL) with anisometropic amblyopia. Lower-right inset, the cyclopean percept of the visual stimuli in binocular viewing. **D**, Mean improvement in stereoacuity as a function of spatial frequency. The black and gray lines show the mean percentage improvement across different spatial frequency groups when those previously stereo-blind participants are excluded and included, respectively. Error bars, one standard error of the mean. Inset, recovery of stereopsis in those previously stereo-blind participants. The black dashed and solid lines show the proportion (and number, n) of participants with measurable stereoacuity before and after the video game intervention, respectively. Since we did not measure stereoacuity in one participant, the total sample size was 20 for this part. Note that the sample size for computing the mean improvement at each spatial frequency setting can be read off from the inset figure.