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Playing three-dimensional video games boosts stereo vision

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Playing two-dimensional video games has been shown to result in improvements in a range of visual and cognitive tasks, and these improvements appear to generalize widely[1–6]. Here we report that young adults with healthy vision, surprisingly, showed a dramatic improvement in stereo vision after playing three-dimensional, but not two-dimensional, video games for a relatively short period of time. Intriguingly, neither group showed any significant improvement in binocular contrast sensitivity. This dissociation suggests that the visual enhancement was specific to genuine stereoscopic processing, not indirectly resulting from enhanced contrast processing, and required engaging in a disparity cue-rich three-dimensional environment.

Specifically, we recruited forty young adult participants with normal vision. They were all non-gamers with no previous video game experience, and none of them had played three-dimensional video games before participating. All participants had excellent visual acuity and stereoacuity. We randomly assigned 21 of them to play off-the-shelf PlayStation three-dimensional first-person shooter video games with large binocular disparities for a total of 40 hours (stereoscopic 3DVG group; twenty 2-hour sessions over 4–5 weeks). For comparison, the other 19 participants were randomly assigned to play identical video games, but in two-dimensional mode for the same time course (non-stereoscopic 2DVG group; twenty 2-hour sessions over 4–5 weeks). Before and after video gaming, we measured their stereoacuity and contrast sensitivity using psychophysical procedures.

Our findings reveal that stereoscopic three-dimensional video game experience boosts depth perception. While the stereoacuity of 2DVG participants remained unchanged after gaming in two dimensions, 3DVG participants had significantly enhanced stereoacuity after gaming in three dimensions (Figure 1A, inset; visual stimuli, random-dot stereograms). It is worth noting that the two video game groups played the same set of video games. The three-dimensional display option, provided in the video game settings, was disabled for the 2DVG group and in turn enabled for the 3DVG group. Only the 3DVG group wore a pair of active shutter three-dimensional glasses and was exposed to stereoscopic depth cues in a virtual three-dimensional gaming environment (two stereo images with binocular disparity; displayed on a 32-in active three-dimensional television screen at a 240 Hz refresh rate); the 2DVG group was not presented with any

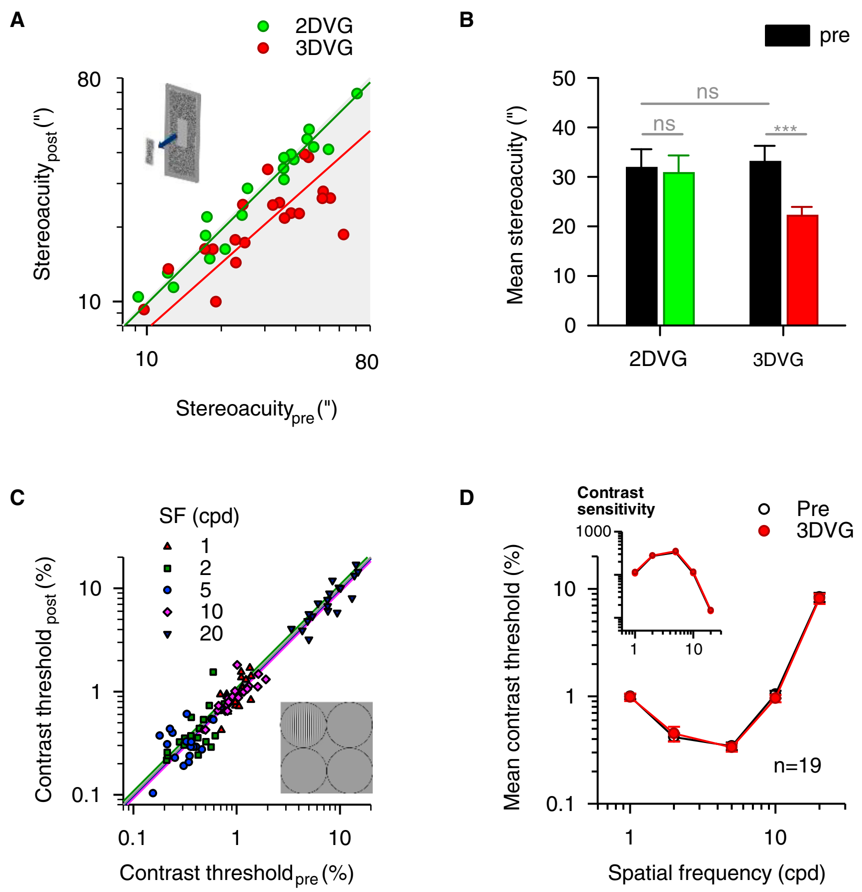

Figure 1. Three-dimensional video game experience enhances depth perception.
(A) Stereoacuity after video game play as a function of baseline stereoacuity. Stereoacuity was measured using random dot stereograms before and after gaming. As illustrated in the inset figure, the visual task was to determine the stereoscopic depth of the central square, in front or behind, relative to the reference background. The regression lines show the mean ratio between $stereoacuity_{post}$ and $stereoacuity_{pre}$ for the two groups. Stereoacuity was expressed in seconds of arc ("). (B) Mean stereoacuity data before and after video game play (black and color columns, respectively). ***, statistically significant difference; ns, no statistically significant difference. Error bars, one standard error of the mean. (C) Contrast threshold before and after playing three-dimensional video games in the 3DVG group. The inset figure illustrates a schematic diagram of the contrast sensitivity test. The visual task was to identify the grating location (top-left/right and bottom-left/right). The regression lines represent the mean ratio between contrast $threshold_{post}$ and contrast $threshold_{pre}$ across spatial frequencies. Note that we did not measure contrast sensitivity in two participants (n = 19). (D) Mean contrast threshold function before and after playing three-dimensional video games. In the inset figure, the threshold data were replotted as contrast sensitivity, the reciprocal of contrast threshold, across spatial frequencies.

stereoscopic depth cue in the video games (one flat image).

Figure 1A illustrates the stereoacuity datasets before and after 40 hours of video game play for individual participants in the two video game groups. The data points of 3DVG participants are mostly scattered below the gray 1:1 reference line in the shaded area - representing better stereoacuity or lower stereothreshold after playing video games in three-dimensions ($stereoacuity_{post}$) when compared with baseline performance ($stereoacuity_{pre}$). Those participants presented with relatively higher baseline stereo thresholds tended to have more improvement in stereoacuity. In contrast, those data points of 2DVG participants are scattered around the unity reference line, meaning that their stereoacuity was roughly the same before and after playing video games in two dimensions.

The mean baseline and post-video game stereoacuity data (black and color bars, respectively) of the two video game groups are displayed in Figure 1B. A two-way repeated measures ANOVA test revealed a statistically significant intervention effect in general ($F = 17.621$, $p < 0.001$). Compared with the baseline session, mean stereoacuity was found to be significantly improved by 33% (a factor of ≈1.5; ratio of mean stereoacuity before and after gaming) after playing three-dimensional video games in the 3DVG group (3DVG, black bar *versus* 3DVG, red bar: Bonferroni $t = 5.544$, $p < 0.001$), but no significant difference in stereoacuity was found after playing two-dimensional video games in the 2DVG group (2DVG, black bar *versus* 2DVG, green bar: Bonferroni $t = 0.52$, $p < 0.606$). It should be noted that there was no significant difference in baseline stereoacuity between the two groups (2DVG, black bar *versus* 3DVG, black bar: Bonferroni $t = 0.274$, $p = 0.785$). The mean psychometric functions for the two groups are shown at the top of Figure S1 in the Supplemental information and the stereoacuity data are summarized as percent improvement in the lower part of the figure (2DVG, green bar, 1.8 ± [SE] 3.0% *versus* 3DVG, red bar, 26.6 ± [SE] 4.8%; the mean calculations were based on percent improvement of individual participants).

These findings suggest that playing stereoscopic three-dimensional video games boosts stereoacuity. We wondered if the immersive three-dimensional video game experience could modify other visual functions as well. It is possible that the sharpened depth perception could be simply resulting from enhanced contrast perception[7,8]. To address this possibility, we also measured contrast sensitivity across a range of spatial frequencies before and after playing video games in the two video game groups (Figure 1C, inset; visual stimuli, sine-wave gratings; see Figure S2 for the data of the 2DVG group).

Importantly, we observed a dissociation between depth perception and contrast perception. Although the 3DVG participants had enhanced stereoacuity, they did not have enhanced contrast sensitivity after gaming in three dimensions. Individual threshold data for the baseline session versus post-3DVG session ($contrast\ threshold_{pre}$ and $contrast\ threshold_{post}$, respectively) are scattered around the gray unity reference line for the five spatial frequencies tested (Figure 1C, 1–20 cycles per degree, cpd), indicating that their contrast sensitivity was essentially unchanged after playing three-dimensional video games.

The mean baseline and post-3DVG contrast thresholds are displayed in Figure 1D. We found no statistically significant change in contrast threshold after gaming (two-way repeated measures ANOVA: $F = 0.423$, $p = 0.524$), and there was no significant interaction between the two factors: contrast threshold and spatial frequency (two-way repeated measures ANOVA: $F = 0.284$, $p = 0.887$). In the inset figure, the threshold data were replotted in terms of contrast sensitivity, the reciprocal of contrast threshold, across spatial frequency.

In brief, our experiments show that playing three-dimensional, but not two-dimensional, video games enhanced stereo vision. The dissociation between depth perception and contrast perception after gaming indicates that the enhancement in stereoacuity was not simply a consequence of improved contrast processing. Engaging in an immersive stereoscopic three-dimensional environment rich in disparity cues is possibly the key to inducing binocular plasticity. In clinical situations, this three-dimensional video game training approach may have special benefit for enhancing stereopsis in people with subnormal binocular vision[9,10].

SUPPLEMENTAL INFORMATION

Supplemental information includes two figures, experimental procedures, author contributions, and references, and can be found with this article online at https://doi.org/10.1016/j.cub.2024.04.032.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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