

Effects of first- and third-person perspectives created using a head-mounted display on dart-throwing accuracy

Yuki Ueyama (✉ ueyama@nda.ac.jp)

National Defense Academy of Japan <https://orcid.org/0000-0002-1415-8875>

Masanori Harada

National Defense Academy of Japan

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Abstract

The first-person perspective (1PP) and third-person perspective (3PP) have both been adopted in video games. The 1PP can induce a strong sense of immersion, and the 3PP allows players to perceive distances easily. Virtual reality (VR) technologies have also adopted both perspectives to facilitate skill acquisition. However, how 1PP and 3PP views affect motor skills in the real world, as opposed to in games and virtual environments, remains unclear. This study examined the effects of the 1PP and 3PP on real-world dart-throwing accuracy after head-mounted display (HMD)-based practice tasks involving either the 1PP or 3PP. The 1PP group showed poorer dart-throwing performance, whereas the 3PP task had no effect on performance. Furthermore, while the effect of the 1PP task persisted for some time, that of task 3PP disappeared immediately. Therefore, the effects of 1PP VR practice tasks on motor control transfer more readily to the real world than do those of 3PP tasks.

Introduction

Video games use either a first-person perspective (1PP) or third-person perspective (3PP). The 1PP promotes immersion and allows performance of precision tasks, such as shooting. Meanwhile, the 3PP provides a wide field of view and allows easy interaction with the surrounding environment. Thus, although less-suited for precision tasks, the 3PP allows players to easily follow the movements of an avatar.

Virtual reality (VR) technologies have become popular for training materials in the fields of aviation (Hays et al. 1992), surgery (Hong et al. 2020; Seymour et al. 2002), and critical care (Koutitas et al. 2020), i.e., fields in which it is difficult to practice the necessary skills safely in the real world. Recently, VR technologies have also been applied to sports and skills training, and their ability to improve real-world performance has been demonstrated to some extent (Michalski et al. 2019; Osti et al. 2020). One study reported a marked improvement in motor skills in the real world following VR training (Gray 2017). According to previous studies, it is important that the virtual environment (VE) be as close as possible to the real-world setting to maximize the transfer of learning, where humans establish motor plans to optimize the sensory information presented during skills training. However, if the practice conditions change, a previously developed motor plan may no longer be appropriate (Miles et al. 2012). In addition, training in the VE is difficult for skills such as throwing that require precise motor coordination and control of force.

An investigation of the effects of the 1PP and 3PP on performance in the VE suggested that the 1PP promoted more accurate interactions with virtual objects, while the 3PP was associated with better spatial awareness (Gorisse et al. 2017). Research has focused on throwing tasks to compare the effects of different perspectives. One study compared the effects of head-mounted display (HMD)-based training using the 1PP and 3PP for a ball-catching task. That study reported that the subjects' performance after training under the 3PP condition was similar to their real-world performance after standard training. In contrast, performance after the 1PP training differed in certain respects from that after the 3PP and

normal training, although there was no absolute performance difference among the training types (Salamin et al. 2010). Another study investigated how different types of visual feedback in a VE affected motor skills, as assessed by a basketball free-throw task (Covaci et al. 2015). Although the VE was associated with underestimation of distances, and the 1PP condition with disrupted distance perception, the performance under the 3PP condition was close to that in the real world. A recent study reported higher accuracy in throwing tasks with whole-body visualization in a VE (Pastel et al. 2020). Nevertheless, how 1PP and 3PP training affect motor performance in the real world, rather than in the VE, remains poorly understood.

The 3PP facilitates depth perception and real-time adjustment of the kinematics of throwing. Thus, although the 3PP is less-suited for precision tasks, we hypothesized that 3PP training could nevertheless facilitate precision throwing. To test this proposition, this study examined the effects of 1PP and 3PP HMD-based practice tasks on real-world dart-throwing ability. Precision throwing is a unique ability of humans (Roach et al. 2013) that has facilitated the development of cognitive abilities, which together with tool use provided an evolutionary advantage (Calvin 1982). Several factors have been shown to affect dart-throwing ability, including cognitive skills (Mendoza and Wichman 1978; Mosley et al. 2017), attentional focus (Lohse et al. 2010; Schorer et al. 2012), arm kinematics (Nasu et al. 2014; Tran et al. 2019), and release timing (Smeets et al. 2002). The mechanisms underlying motor skill acquisition have also been explored (Ikegami and Ganesh 2014; van Beers et al. 2013). A recent study demonstrated that adjustment of the kinematics of throwing may be the most important factor in the acquisition of new throwing skills, largely because this strategy is robust to temporal variability arising from neuromotor noise, whereas the strategy of adjusting release timing is more sensitive to that noise (Zhang et al. 2018). Neuromotor noise introduces uncertainty in movements (Ueyama 2014; Ueyama and Miyashita 2013), and robustness to this noise is important for the brain to optimally tune motor activity (Ueyama 2017a; Ueyama and Miyashita 2014).

In our experiment, subjects were asked to throw darts in a practice task using a 1PP or 3PP view, as provided by an HMD. Dart-throwing performance was compared before and after completing the 1PP or 3PP practice task. The results showed that dart-throwing performance did not change after the 3PP practice. However, the effect of the 1PP practice briefly persisted after removing the HMD, whereas that of the 3PP practice was immediately lost. Therefore, although our hypothesis was rejected, the results suggest that the degree of transfer of skills to the real world differs between the 1PP and 3PP views.

Methods

We divided the subjects into 1PP and 3PP groups. Each group threw a dart 60 times in total; the middle third of the throws were performed while wearing the HMD, which provided a 1PP or 3PP view (Fig. 1a–b; Electric Supplementary Material ESM_1.mp4). All

experimental procedures were approved by the Ethics Review Board of the National Defense Academy of Japan.

2.1 Subjects

Forty academy students (two females) aged 19–23 years were recruited; six were left-handed. All subjects had normal or corrected-to-normal vision, and reported no history of neurological or psychiatric, and provided written informed consent prior to inclusion in the study. They were randomly allocated to the 1PP or 3PP group (both $n = 20$).

2.2 Apparatus

A commercially available soft dartboard was used, positioned at a height of 1.73 m. The distance from the throwing line to the dartboard was 2.44 m (Fig. 1c). The subjects threw standard plastic-tipped darts of the same size and weight. The HMD device was a Vive Pro (HTC, New Taipei, Taiwan; resolution: $1,400 \times 1,600$ pixels/eye; field of view: 110° ; angular resolution: 14.5 pixels per degree). A stereo camera system (640×480 pixels) was mounted on the front of the HMD to provide the 1PP view (Fig 1d). For the 3PP view, a 360° camera (Theta V; Ricoh, Tokyo, Japan) was set 1.70 m behind the throwing line on the right-hand side (135°). The resolution of the video streamed from the 360° camera was $3,840 \times 1,920$ pixels, and the angular resolution was 5.3 pixels per degree. The body representation is often viewed from a distance in the 3PP, often from behind the body, or from the side or above (Seinfeld et al. 2020). We positioned the camera so that the arm posture and dartboard were not obscured from view by the subjects' body, similar to the camera position in some 3PP shooting video games (e.g., Biohazard 4–6; CAPCOM, Osaka, Japan). The HMD displayed images from the 360° camera synchronized with the subjects' head movements, and the images were processed in real time using a 3D game engine (Unity; Unity Technologies, San Francisco, CA, USA). The view could be switched from the 1PP to the 3PP by the experimenter. The camera angles and heights were adjusted to match the centers of the dartboards in both the 1PP and 3PP views during throwing, and subjects were asked not to change their head position between the 1PP and 3PP views. The

experiment was designed so that the subjects in both groups threw the darts in the same manner.

2.3 Procedure

The experiment was divided into three phases (pre-intervention, intervention, and post-intervention). Each phase comprised five blocks of four dart throws (20 throws in total per phase). The subjects always threw the dart with their dominant hand and aimed for the center of the dartboard (i.e., bull's-eye). The distance from the bull's-eye to the dart, measured manually by the experimenter, served as the performance indicator. There was a 3-minute rest period between task phases; subjects could also rest while the measurements were being collected.

Before the experiment, the subjects threw 5–10 darts for familiarization with the laboratory environment (Fig. 1e). In the pre-intervention phase, the subjects were instructed to throw the dart at the bull's-eye 20 times, as accurately as possible. In the intervention phase, the subjects wore the HMD and threw 20 darts under the 1PP or 3PP condition. In the 3PP group, the 3PP view was only presented during throwing: the view was switched from the 1PP to the 3PP just prior to the dart-throw, when the subjects signaled that they were ready to throw, and returned to the 1PP view soon after the dart reached the dartboard. The effects of the intervention were measured during the post-intervention phase. In this phase, the subjects removed the HMD and threw 20 darts in the same way as in the pre-intervention phase.

2.4 Analysis

We evaluated the effects of the 1PP and 3PP by comparing the dart-throwing performance between the pre- and post-intervention phases. We excluded the data of one 3PP group subject from the analysis because they failed to hit the dartboard twice during the pre-intervention phase. All other subjects hit the dartboard with all darts in the pre-intervention phase. Thus, the final analysis included the data of 20 and 19 subjects in the 1PP and 3PP groups, respectively. In the intervention and post-intervention phases, trials where the darts did not hit the dartboard or missed it by > 200 mm, which is outside of the “play area” of

the dartboard, were recorded as “failed trials.” The failed trials were combined with 200-mm misses in subsequent analyses.

2.4.1 Model-based analysis

We modeled the trial-by-trial performance of the 1PP and 3PP groups to elucidate the learning process in the VR practice tasks. Then, we assumed that the variability in dart-throwing performance converged in the pre-intervention phase (van Beers et al. 2013). Thus, differences in performance between the post- and pre-intervention phases were attributed to the intervention phase. The error on the k^{th} trial, y_k , was defined as

$$y_k = c \cdot e_k + d, \quad (1)$$

where c and d are free parameters representing compliance and offset, respectively. The error y_k is the absolute error, and indicates the distance from the bull’s-eye to the dart. The error e_k is the internal error for adaptation, and is denoted by

$$e_k = |p_k - x_k|, \quad (2)$$

where p_k and x_k are perturbation and memory, respectively. Subjects estimate perturbation p_k through a motor adaptation process, similar to memory x_k , and the error e_k affects their behavior directly. The perturbation p_k is a binary signal induced by the 1PP or 3PP view, and took a value of 1 during the intervention phase and 0 at all other times:

$$p_k = \begin{cases} 1 & \text{intervention phase} \\ 0 & \text{pre-/post-intervention phase} \end{cases} \quad (3)$$

Here, $k = 21, 22, \dots, 40$ during the intervention phase. Any other values of k indicate the pre- or post-intervention phase.

The memory, x_k , reflects the adaptation ratio for perturbation. It is assumed to be in an equilibrium state $x_k = 0$ during the pre- and post-intervention phases, and is only

affected by the error induced by perturbation (as a motor adaptation process) (Ueyama 2017b). We assumed that error was determined by memory and perceived as the prediction error e_k , and excluded execution noise because the brain seems to correct errors associated with previous motor planning rather than actual performance (van Beers 2009). We assumed that memory only decayed in the post-intervention phase after removing the perturbation, and had a different time constant from that of the intervention phase. Thus, memory updating is represented by

$$x_{k+1} = \begin{cases} a_1 \cdot x_k + b \cdot e_k & \text{intervention phase} \\ a_2 \cdot x_k & \text{pre-/post-intervention phase} \end{cases} \quad (4)$$

where a_1 and a_2 are the retention rates during the intervention phase and at all other times, respectively, and b is the rate of adaptation to the perturbation in the intervention phase. The retention rate a_2 indicates the magnitude of after-effects of the intervention phase.

The five parameters a_1 , a_2 , b , c , and d were estimated to fit the model to the experimental data, while minimizing the squared error using the interior-point method with the constraints $0 \leq a_1, a_2, b, c \leq 1$. The coefficient of determination R^2 was calculated in the standard way.

2.4.2 Statistical analysis

Means and standard deviations (SDs) were calculated for all 20 trials, for each subject, in the pre- and post-intervention phases, and the difference was evaluated using a two-tailed paired t -test (as a measure of the effects of the intervention phase). The data of the 1PP and 3PP groups were compared using a two-tailed Welch's t -test.

A standard bootstrap technique was applied to generate confidence intervals for trial-by-trial performance. Then, we resampled the data 200 times, deriving mean values for each resampling.

2.5 Validation of size and distance perception

We were concerned about the validity of size and distance perception in our study because the 3PP view in our experiment was not stereoscopic and the 1PP stereo camera had a lower resolution than the 3PP 360° camera. Therefore, we performed an additional experiment to validate the perception of distance and size in 1PP and 3PP.

We included 10 healthy subjects (age: 21–29 years; height: 1.65–1.82 m; all males) in this experiment who were not part of the main experiment. These subjects observed white paper cubes in either 1PP or 3PP view created by the HMD. They were asked to open their thumb and index fingers to imitate grasping of the cubes. We measured the width between their thumb and index finger manually, as a measure of the perceived size of the cubes. Each cube was displayed with one of the following side lengths: 50, 60, 70, 85, or 100 mm (Fig. 2a). Each cube was displayed on a cork sheet at a height of 0.95 m and distance of 0.80, 1.60, or 2.40 m (Fig. 2b). The subjects were required to reply with their estimated size of the cubes 30 times (2 perspectives \times 3 distances \times 5 sizes). Half of the subjects performed this task in 1PP view before the 3PP view, and the other half performed the task in the reverse order. The cubes were displayed at each location in a random manner. The HMD images were blacked out before and after each trial. After observing the cubes of all sizes at each location, we asked the subjects to estimate the number of footsteps (until the tenth place) required to reach the cube. The number of steps was used to calculate the perceived distance by a simple formula ($\text{distance} = \text{steps} \times \text{height} \times 0.37$) involving the step length, step height, and a slow walking speed.

We calculated differences in size and distance between the subjects' reports and the actual values. We performed a two-way repeated-measures ANOVA (2 perspectives \times 3 distances) to evaluate the effects of the 1PP and 3PP on these errors. Scheffe's multiple comparison test was used for the post hoc analysis, with an alpha level at 0.05.

Results

3.1 Trial-by-trial performance

The 1PP and 3PP groups showed constant errors during the pre-intervention phase (Fig. 3a). There was no significant difference in dart-throwing performance between the 1PP and 3PP groups during the pre-intervention phase ($p = 0.93$; Fig. 4a). The error magnitude increased in both groups at the beginning of

the intervention phase and then gradually decreased. The number of errors continued to decrease gradually in the 1PP group during the post-intervention phase, but not in the 3PP group. Memory decayed more slowly during the post-intervention phase in the 1PP than 3PP group (Fig. 3b), i.e., the post-intervention phase a_2 values were 0.83 ($R^2 = 0.72$) and 0.22 ($R^2 = 0.91$), respectively (Table 1). The mean retention rate was significantly higher in the 1PP group than the 3PP group (0.55 ± 0.35 and 0.31 ± 0.32 mm, respectively; $p = 0.035$; Fig. 3c).

3.2 Comparison of the pre- and post-intervention phase dart-throwing performance

We compared the error between the pre- and post-intervention phases to evaluate the effects of the intervention (Fig. 4a). In the 1PP group, the mean post-intervention phase error magnitude was larger than that during the pre-intervention phase (66.9 ± 10.3 and 60.2 ± 7.1 mm, respectively; $p = 0.0046$). In contrast, the 3PP group showed a slightly, but not significantly, smaller mean error magnitude post-versus pre-intervention (57.8 ± 8.1 and 60.4 ± 7.0 mm, respectively; $p = 0.21$).

The 1PP and 3PP HMD practice tasks had different effects on performance in the post-intervention phase. The mean changes in performance, computed by subtracting pre-intervention phase scores from those in the post-intervention phase, were 6.7 ± 9.6 and -2.6 ± 8.9 mm in the 1PP and 3PP groups, respectively; this difference was significant ($p = 0.0026$; Fig. 4b).

3.3 Size and distance perception

In the HMD-based tasks, there was a difference in mean size perception values between 1PP and 3PP only for near objects (Fig. 5a; 1PP: -0.8 ± 9.0 , 5.5 ± 6.5 , and 2.9 ± 6.5 ; 3PP: -10.5 ± 5.9 , 4.7 ± 8.6 , and 1.2 ± 6.1 mm for near [0.8 m], moderate [1.6 m], and far [2.4 m] distances, respectively). The two-way repeated ANOVA revealed significant main effects of perspective ($F_{(1,9)} = 8.32$, $p = 0.018$, $\eta^2 = 0.46$) and distance ($F_{(1,9)} = 6.38$, $p = 0.032$, $\eta^2 = 0.27$), and a significant interaction effect ($F_{(1,9)} = 5.83$, $p = 0.039$, $\eta^2 = 0.26$). Using Scheffe's test, we found a significant difference between the near distance and other distances (moderate: $p = 0.050$; far: $p = 0.0016$) in 3PP. The difference between the distances was not statistically significant in 1PP ($p > 0.20$). There was a difference between both perspectives for the near distance ($p = 0.0079$), but not for the other distances ($p > 0.45$).

The mean error and variance of the perceived distance gradually increased with an increase in the actual distance in 1PP and 3PP (1PP: 0.14 ± 0.26 , 0.18 ± 0.60 , and 0.72 ± 0.85 ; 3PP: -0.15 ± 0.28 , 0.20 ± 0.43 , and 0.81 ± 0.67 m for near, moderate, and far distances, respectively; Fig. 5b). Two-way repeated ANOVA revealed a significant main effect of distance ($F_{(1,9)} = 6.56$, $p = 0.031$, $\eta^2 = 0.42$) and a significant interaction effect ($F_{(1,9)} = 7.62$, $p = 0.022$, $\eta^2 = 0.39$), but there was no significant main effect of perspective ($F_{(1,9)} = 4.25$, $p = 0.069$, $\eta^2 = 0.19$). Scheffe's test showed significant differences between the

pairs of distances in 1PP and 3PP ($p < 0.05$), except for near and moderate distances in 1PP ($p = 0.17$). There were no significant differences between 1PP and 3PP for any distance ($p > 0.65$).

Discussion

The objective of this study was to clarify the effects of practice HMD-based tasks with a 1PP and 3PP view on a real-world skill, i.e., dart throwing. Subjects' performance declined while wearing the HMD regardless of the type of perspective, but showed gradual adaptations to the environment. The effects of the practice task persisted after removal of the HMD only in the 1PP group, who showed poorer performance than before the intervention. In contrast, the 3PP group showed almost the same performance before and after the HMD intervention. This effect was not caused by simple visual displacement, because it was reported that a large amount of visual displacement induced a greater decrease in adaptation magnitude but showed a larger after effect (Lee and Park 2020). Thus, while the 1PP HMD practice task affected real-world performance, the 3PP task did not. According to the model-based analysis, the effect of the 1PP HMD practice persisted for a while, reflected in the higher retention rate of that group compared to the 3PP group; in the latter group, the effect of the practice disappeared immediately. The difference in perception of size and distance between 1PP and 3PP was minimal, except for distances less than 1.6 m. Because the dartboard was set 2.44 m from the subjects, according to the convention for soft darts games, we believe that differences in the perception of size and distance between 1PP and 3PP had little effect on our results.

The 1PP might be preferable for inducing a sense of ownership of a virtual body (i.e., avatar) in a VE (Slater et al. 2010), although both the 1PP and 3PP can induce a strong feeling of spatial presence (Goris et al. 2017). It appears that, via the 1PP, a sense of body ownership can be transferred to others' bodies (i.e., VR body swapping) (Petkova and Ehrsson 2008). In contrast, with the 3PP, a sense of body ownership may be absent, such that sensations are experienced as if they are outside the body (Ehrsson 2007). Even when different techniques are used to induce a sense of body ownership in 3PP, the sense of body ownership remains stronger in 1PP (Galvan Debarba et al. 2017). The sense of body ownership interacts with the sense of agency, by which some actions are self-generated (Arzy and Schacter 2019). The sense of agency arises directly from an internal model (Engbert et al. 2008; Moore and Haggard 2008; Moore et al. 2009; Vogeley and Fink 2003), represented in the cerebellum and associated with motor adaptation (Wolpert et al. 1998). Thus, the difference in the effects of the 1PP and 3PP practice tasks in this study might be attributable to the presence (or absence) of senses of agency and body ownership.

The performance of the 1PP group decreased during the intervention phase, even though the visual information provided therein was the same as in the pre-intervention phase. A previous study reported a similar result (Schorer et al. 2012). Although visual displacement problems are caused by the distance between a front-mounted camera and the human eye inducing visuomotor performance deterioration (Lee and Park 2020), our apparatus is designed to suppress this problem by matching the positions of the camera and the eyes. Therefore, this finding could be explained by two factors. First, some subjects

had to change the kinematics of their throwing style when wearing the HMD; some held their hands in front of their face in the pre-intervention phase, but could not assume the same posture in the intervention phase because of the HMD. Second, because the resolution of the camera was very low compared to that of the HMD, the 1PP group was essentially rendered near-sighted. A previous study reported that 3PP practice had a similar effect on real-world performance to the 1PP practice (Salamin et al. 2010). Our results seem to contradict this, where the effects of the 3PP practice disappeared immediately while and those of the 1PP practice persisted. We suggest that the reason why the 3PP and 1PP practices had similar effects on performance in the previous study was that, while the effects of the 3PP practice disappeared immediately, any advantage of the 1PP practice would have been negated by issues with the HMDs, as in our experiment.

Although a 360° camera was used to create the 3PP view in this study, the camera could not reproduce stereoscopic vision. The perception of size and distance (except near distance) is likely similar between the 1PP and 3PP views. Therefore, stereoscopic vision likely would have reduced error during the intervention phase, but we suggest that practice does not affect real-world performance, as indicated by this result, due to the lack of a sense of body ownership.

In summary, the 3PP and 1PP HMD-based practice tasks had different effects on dart-throwing performance. Although the effects of the 1PP task persisted for some time after removing the HMD, those of the 3PP task did not. Therefore, we suggest that 1PP practice tasks can affect real-world motor control, while the effects of 3PP practice tasks may be limited by the lack of any sense of agency and body ownership.

Declarations

Author contributions

Y.U. designed the study, performed the experiments, collected and analyzed the data, and wrote the manuscript. Y.U. and M.H. discussed the results, and approved the final manuscript.

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Tables

Table 1. Estimated values of the model parameters fitted to the experimental data, as indicators of trial-by-trial performance.

		a_1	a_2	b	c	d
1PP	Mean behavior	0.95	0.83	0.071	0.040	0.060
	Subject mean \pm SD	0.67 ± 0.37	0.55 ± 0.35	0.41 ± 0.34	0.058 ± 0.032	0.060 ± 0.012
3PP	Mean behavior	0.81	0.22	0.14	0.090	0.058
	Subject mean \pm SD	0.61 ± 0.34	0.31 ± 0.32	0.32 ± 0.28	0.100 ± 0.031	0.056 ± 0.014

Figures

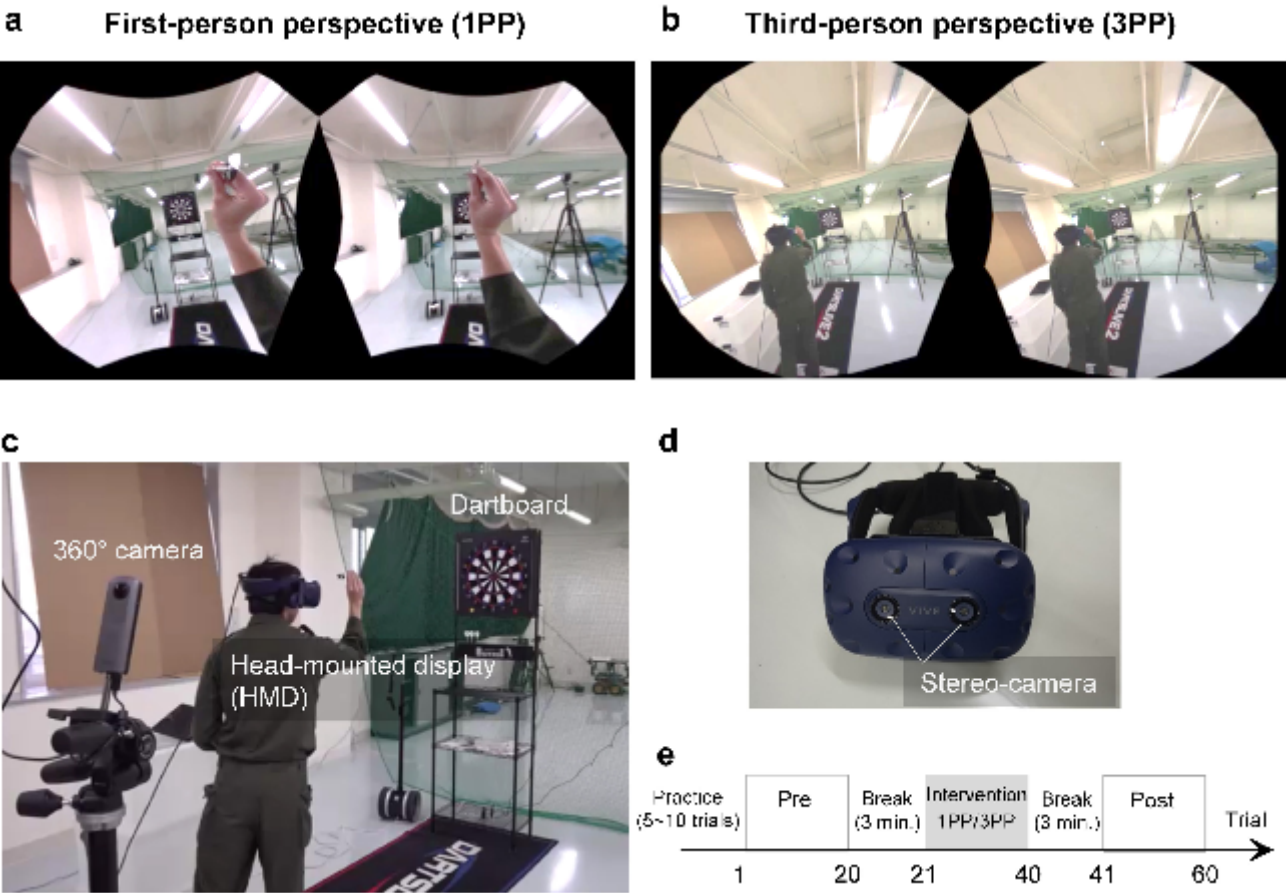


Figure 1

Experimental setup. (a) First-person perspective (1PP) and (b) third-person perspective (3PP) views. The left and right images in each panel are projected to the respective eye of the participant through a head-mounted display (HMD). (c) Experimental apparatus and environment. (d) The stereo camera system mounted on the front of the HMD. (e) Experimental procedure.

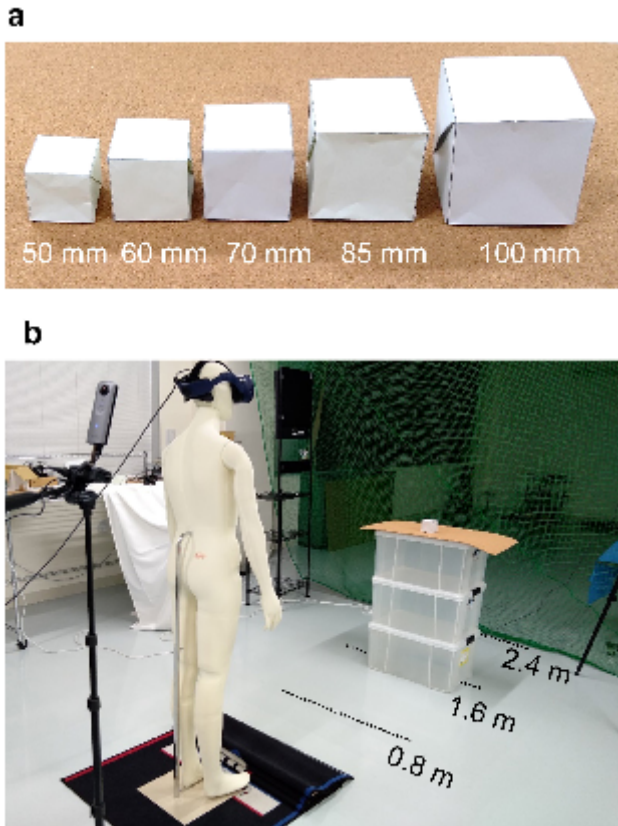


Figure 2

Validation experiment for size and distance perception. (a) Five cubes differing in size were presented to the subjects. (b) Experimental setup. The cubes were located at one of three distances (near: 0.8 m; moderate: 1.6 m; far: 2.4 m) from the subjects. There were no marks or symbols on the floor to indicate the distance.

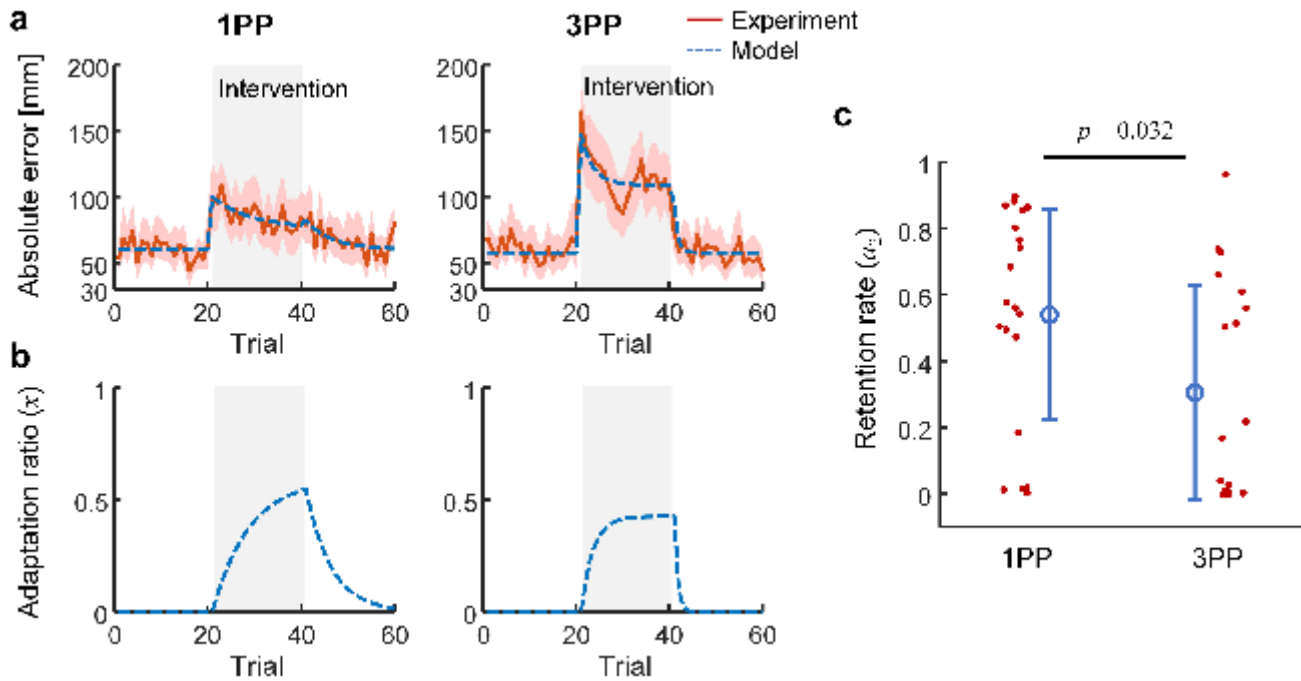


Figure 3

Dart-throwing performance according to model-based analysis. (a) Trial-by-trial performance across subjects. The red line and shaded area indicate mean and 95% confidence interval data, respectively, derived from the experiments. The blue dotted line shows the model estimates. (b) Adaptation ratios. (c) Comparison of the mean retention rates of the 1PP and 3PP groups during the post-intervention phase. The vertical bars are standard deviations (SDs). The red dots show the data of individual subjects. The p-value above the horizontal line is for the retention rate comparison between the 1PP and 3PP groups.

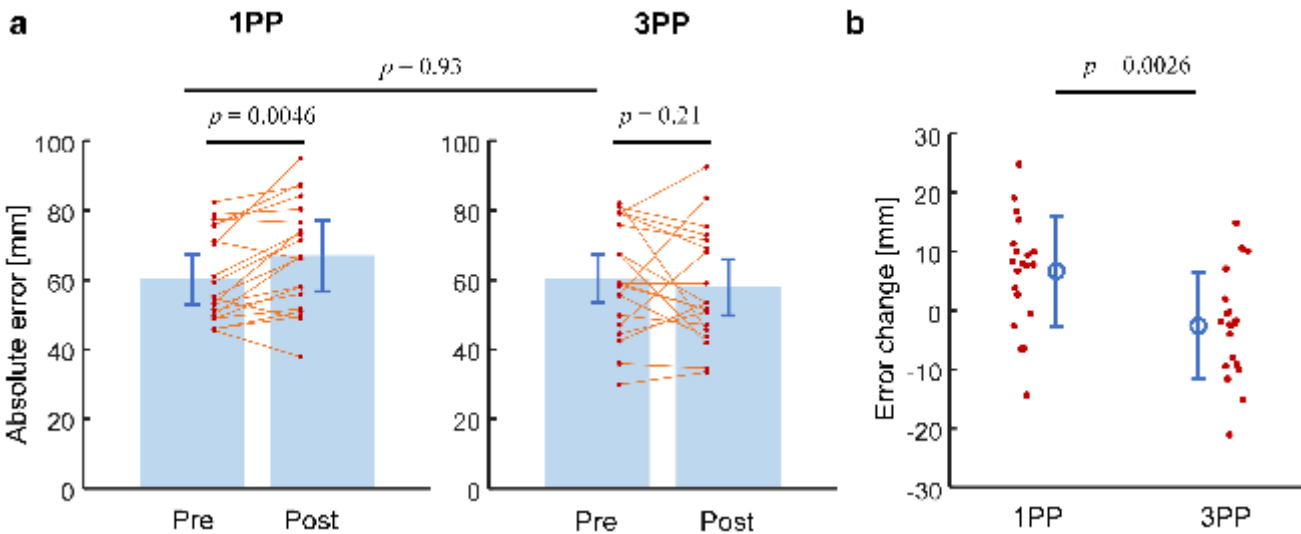


Figure 4

Comparison of performance between the pre- and post-intervention phases. The vertical bars indicate the SDs. The red dots show the data of individual subjects. The p-values above the horizontal lines are for

the comparisons of pre- and post-intervention error, or change in error, between or within groups. (a) Mean absolute errors. (b) Changes in performance from the pre-intervention phase to the post-intervention phase.

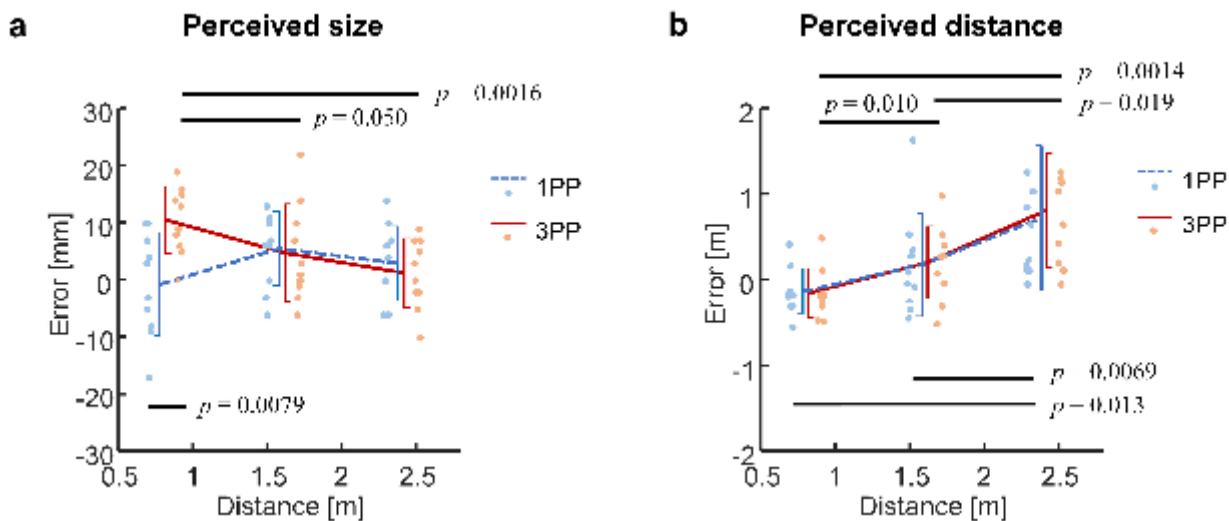


Figure 5

Effects of perspective on (a) size and (b) distance perception. The lines and vertical bars indicate the mean and SD, respectively. The dots show the data of individual subjects. The horizontal bars and accompanying values indicate the statistical differences and p-values computed by Scheffe's test.

Supplementary Files

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