

ORIGINAL ARTICLE

## 3D technology of Sony Bloggie has no advantage in decision-making of tennis serve direction: A randomized placebo-controlled study

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### Abstract

This study aimed at exploring whether 3D technology enhances tennis decision-making under the conceptual framework of human performance model. A 3 (skill-level: varsity, club, recreational) × 3 (experimental condition: placebo, weak 3D [W3D], strong 3D [S3D]) between-participant design was used. Allocated to experimental conditions by a skill-level stratified randomization, 105 tennis players judged tennis serve direction from video scenarios and rated their perceptions of enjoyment, flow, and presence during task performance. Results showed that varsity players made more accurate decisions than less skilled ones. Additionally, applying 3D technology to typical video displays reduced tennis players' decision-making accuracy, although wearing the 3D glasses led to a placebo effect that shortened the decision-making reaction time. The unexpected negative effect of 3D technology on decision-making was possibly due to participants being more familiar to W3D than to S3D, and relatedly, a suboptimal task-technology match. Future directions for advancing this area of research are offered.

**Keywords:** 3D technology, decision-making, tennis, placebo effect, subjective experience

### Highlights

- 3D technology augments binocular depth cues to tradition video displays, and thus results in the attainment of more authentic visual representation. This process enhances task fidelity in researching perceptual-cognitive skills in sports.
- The paper clarified both conceptual and methodological difficulties in testing 3D technology in sports settings. Namely, the nomenclature of video footage (with/without 3D technology) and the possible placebo effect (arising from wearing glasses of 3D technology) merit researchers' attention.
- Participants varying in level of domain-specific expertise were randomized into viewing conditions using a placebo-controlled design. Measurement consisted of both participants' subjective experience (i.e., *presence*, *flow*, and *enjoyment*) and objective performance (i.e., accuracy and reaction time) in a decision-making task.
- Findings revealed that wearing glasses of 3D technology resulted in a placebo effect that shortened participants' reaction times in decision-making. Moreover, participants' decision-making accuracy decreased when viewing video scenarios using 3D technology. The findings generated meaningful implications regarding applying 3D technology to sports research.

Three-dimensional (3D) technology adds binocular depth cues to traditional video displays to attain a more authentic content representation (Miles, Pop, Watt, Lawrence, & John, 2012). 3D viewership and opinion seems to have increased since *Avatar* in 2009 (Kehr, 2010). The positive trend toward 3D technology spawned research interest across domains, such as movie-watching (Yang et al., 2012) and spatial assessment (Seipel, 2013). The present study aimed at exploring the utility of 3D

technology in sport context. However, before discussing 3D technology in sport, two issues must be addressed because they pose difficulty in assessment of 3D technology.

First, the semantic reference of several concepts requires clarification. 2D is defined as projecting a conceptual two-dimensional geometry on a two-dimensional display surface (as in a road map; Seipel, 2013). Ambiguously, 2D is also used to label visual display of a common video footage in

the literature, though such a display is classified as *Weak 3D* (or Monoscopic 3D; W3D). W3D refers to projecting a conceptual three-dimensional geometry on a two-dimensional display surface with spatial cues implied through shading, occlusion, relative sizes, and other techniques (Seipel, 2013). Another related term is *Strong 3D* (or Stereoscopic 3D; S3D), which is a more representative label for a visual display applying 3D technology to a W3D display (as in a 3D movie). S3D goes beyond W3D by incorporating binocular disparity, convergence, and accommodation techniques in presenting spatial cues (Yang et al., 2012). This definitional distinction is important because 2D–W3D findings can be mistakenly interpreted as W3D–S3D findings, and vice versa. Second, comparing participants' responses under S3D and W3D may not help infer the value of the binocular depth cues offered by the 3D technology. Namely, S3D viewers must wear either active or passive glasses to view the stimuli (for a review on glasses, see Read & Bohr, 2014), whereas W3D viewers do not. Such a procedural difference may confound conclusions from W3D–S3D comparison because wearing glasses tends to affect viewers, resulting in a placebo effect.

Without controlling for the placebo issue, sport researchers recently tested 3D technology by contrasting participants' decision-making outcomes (i.e. accuracy and latency) between S3D and W3D. Lee et al. (2013) showed that athletes had no performance improvement in intercepting a charging opponent under either S3D or W3D conditions. However, Hohmann, Obelöer, Schlapkohl, and Raab (2016) found female handball athletes made better decisions (i.e. reduced latency while maintaining accuracy) following S3D training than those following W3D training. In another study, Put et al. (2014) investigated assistant soccer referees' offside judgment and found S3D offside scenarios resulted in higher decision-making accuracy than W3D scenarios, but this benefit was not replicated in a following frame recognition task requiring memory and mental abstraction. Although extant S3D–W3D studies in sport contributed to the understanding of 3D technology, additional questions emerged due to design issues. Specifically, whereas Hohmann et al. (2016) used between-participant design without randomization, Lee et al. (2013) and Put et al. (2014) employed within-participant design in which the counter-balanced procedure could not control for a crossover effect, especially given the concern of a placebo. Therefore, the overall evidence of this area has been limited and inconclusive, but it has highlighted the relevance of 3D technology to the perceptual–cognitive skills in sport.

*Perceptual–cognitive skill* (PCS), such as anticipation and decision-making, represents one's ability to integrate environmental information with existing knowledge so that an appropriate response can be made and executed (Marteniuk, 1976). According to the *human performance model*, information flows across five systems, including environmental, sensory, perceptual, cognitive, and motor system. The perceptual–cognitive process involves both perceptual and cognitive systems so that sensory input and stored knowledge can interact with each other prior to response generation (Marteniuk, 1976). In sport, PCS is crucial for high-level performance (Mann, Williams, Ward, & Janelle, 2007). For example, when required to judge serve directions from pre-recorded W3D video clips identified using temporal and/or spatial occlusion paradigms, experts demonstrated higher decision-making accuracy and/or shorter reaction time (RT; Jackson & Mogan, 2007; Williams, Ward, Knowles, & Smeeton, 2002).

Sport research of expertise effect in PCS can benefit from involving 3D technology in stimulus presentation. 3D technology is a visual display technology assisting to build virtual environment (VE) in laboratory settings (Miles et al., 2012). Steuer (1992) conceptualized the contribution of media technologies to VE based on two dimensions: *vividness* (i.e. richness of a mediated environment) and *interactivity* (i.e. degree to which users can modify a mediated environment in real time). 3D technology is classified as being stronger in vividness than interactivity. It enhances sensory input and thus allows for observing PCS in tasks of increased fidelity. Fidelity is the similarity between the laboratory task and the field task (Hays & Singer, 1989), and the lack of fidelity represents a criticism towards sport research of expertise effect in PCS (Abernethy, Thomas, & Thomas, 1993). Therefore, sport research involving 3D technology is justified by limiting the fidelity criticism. Moreover, researchers argued that as fidelity increases the expertise effect in PCS would also increase (Williams, Davids, Burwitz, & Williams, 1992). With 3D technology and participants of varying skill-level, researchers may test this argument by comparing expertise effect in PCS between S3D and W3D presentation. However, an implicit assumption for 3D technology to benefit sport research is that tasks using S3D have higher fidelity than those using W3D. To evaluate the validity of this assumption, it is recommended to measure subjective experience of 3D technology (Lee et al., 2013).

The measurement of *presence*, *flow*, and *enjoyment* perception provides information required to validate the fidelity-enhancing assumption of the 3D technology. Presence<sup>1</sup> is a perception of “being there” in VE

rather than in the immediate physical environment (Steuer, 1992). Therefore, fidelity is enhanced when task performers perceive strong presence. Flow is a positive experiential state during a task where performer's skill-level is challenged to a comparable amount of external demand (Csikszentmihalyi, 1975). When participants experience flow during task performance, they are considered mentally immersed in the task environment (Csikszentmihalyi, 1988). Thus, whereas presence captures the attentional and perceptual facets of VE experience, flow holistically reflects the cognitive-emotional-motivational impact of the experience (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2004). Lastly, enjoyment is worth consideration as an important and distinctive emotional experience for users of 3D technology (Yang et al., 2012). Based on the human performance model, if 3D technology increases fidelity by enhancing visual sensory input, participants should have stronger subjective responses (especially for presence) in S3D than S3D.

The present study aimed to investigate whether the application of 3D technology to video stimuli presentation enhanced decision-making in sport. Participants were asked to judge tennis serve directions from a returner's perspective after video clips were occluded at the racket-ball contact. Based on previous review, we made corresponding efforts to extend sport research of 3D technology by (a) including a placebo group where participants wear 3D glasses while viewing W3D video clips; (b) recruiting tennis players of varying skill-levels and randomizing them into video presentation conditions; and (c) measuring not only the decision-making outcomes but also subjective experiences during the task. We hypothesized that both S3D and domain-specific expertise will facilitate anticipatory decision-making and the largest effect on decision-making will occur when both factors are present. We also hypothesized

that, compared to W3D and placebo conditions, S3D will result in improved subjective experience during the task.

## Method

### Participants

The current study included 105 tennis players. NCAA Division I athletes and university club tennis members were recruited via coach invitations. Recreational tennis players (who never play competitive tennis or join an organized tennis group) were recruited from a participant pool within the university or by invitation during tennis playing at local courts (see Table I for demographics). All participants gave informed consent and the research protocol was approved by the university ethics committee. Two participants' data were dropped from the analysis because one had an average RT 4 SDs longer than the grand mean, and the other did not complete all the measurement.

### Task design

Participants were asked to decide serve directions after watching video clips recorded from a returner's perspective. They were required to respond as quickly and accurately as possible by pressing either "F" key (indicating "left") or "J" key (indicating "right") using index fingers on a keyboard. Both S3D and W3D video clips were recorded by a 3D camcorder<sup>2</sup> (Sony Bloggie 3D, Sony, Tokyo, Japan). The camcorder was positioned in the centre of the half service lines on both ad and deuce courts at a height of 150 cm. The 3D camcorder was adjusted to converge approximately 1 m in front of the net. The tennis video clips featured one female and one male (both of whom were past varsity athletes) as servers.

Table I. Demographic information of the sample

Variables	Skill-level			Experimental condition			Total (Mean ± SD) or Total (%)
	Recreational (Mean ± SD) or Total (%)	Club (Mean ± SD) or Total (%)	Varsity (Mean ± SD) or Total (%)	Placebo (Mean ± SD) or Total (%)	W3D (Mean ± SD) or Total (%)	S3D (Mean ± SD) or Total (%)	
<i>n</i>	29	38	36	32	36	35	103
Participant age	22.0 (3.6)	22.3 (7.5)	20.3 (3.1)	21.4 (5.2)	21.7 (4.3)	21.7 (6.5)	21.6 (5.3)
Years of experience	3.1 (4.6)	10.2 (6.8)	13.5 (4.4)	9.4 (7.4)	11.4 (6.7)	10.2 (5.0)	10.4 (6.4)
Tennis ability	3.4 (2.2)	7.0 (1.1)	8.1 (1.0)	6.5 (2.5)	6.0 (2.4)	6.7 (2.4)	6.4 (2.4)
Gender							
Male	11 (10.7%)	23 (22.3%)	21 (20.4%)	18 (17.1%)	20 (19.4%)	17 (16.5%)	55 (53.4%)
Female	18 (17.5%)	15 (14.6%)	15 (14.6%)	14 (14.3%)	16 (15.5%)	18 (17.5%)	48 (46.6%)

Notes: Years of experience = years spent in playing tennis; tennis ability = self-rating of tennis skill-level on an 11-point Likert item ranging from 1 (completely novice) to 11 (ATP champion).

The female server was right-handed and the male server was left-handed. A total of 80 serves were filmed from them. Later, 40 video clips (with all factors balanced) were selected for the formal experiment. Additionally, 20 practice serves were recorded from another male tennis player on a different tennis court. The camera was placed 130 cm inside the baseline and 127 cm inside the singles line at a height of 150 cm. Eight video clips were later selected into the practice phase of the experiment. The practice consisted of 10 video clips and the last two video clips were from the two servers of formal experiment, respectively. During practice, correct answers were given to participants immediately after they responded to each video. All the video clips were edited to start with the ball toss and were occluded by a 2 s black screen at the frame of ball-racket contact.

### Measures and materials

*Response accuracy and RT.* Using a laptop, the task was presented on a 55-inch TV (55G2-UG, LG, Seoul, South Korea) with a 1920 × 1080 resolution and a refresh rate of 60 Hz. The TV allowed for playing S3D video clips with passive 3D glasses (LG Cinema 3D glasses, LG, Seoul, South Korea). The task presentation followed the sequence of (a) blue screen, (b) practice phase (where the video clips were presented in a pre-established order), (c) blue screen, (d) formal experiment (where the order of video presentation was randomized), and (e) blue screen. The three blue screens were used to lock the response keyboard for experimental instructions. Response accuracy was represented by correct trial percentage and RT was calculated by averaging trial duration between video occlusion and participant response.

*Subjective experience.* Participants' enjoyment was measured using a modified version of the Enjoyment Questionnaire (EQ; Raney, 2002). Phrasing of the items was adapted to reflect the topic of current materials.<sup>3</sup> Raney (2002) reported an observed alpha coefficient of .96 for EQ. Presence was measured using the Slater, Usoh and Steed Questionnaire (SUS; Slater, Usoh, & Steed, 1995). The term describing simulated object in each item of SUS was replaced by "tennis court". The observed omega coefficient of SUS was .85 (Bae et al., 2012). Flow was measured using Core Flow Scale (CFS; Martin & Jackson, 2008). Martin and Jackson (2008) applied CFS in a sport setting and reported an observed omega coefficient of .92.

### Procedures

The experiment was conducted in a dark room where one participant and two researchers were present.

Upon arrival, the participant read and signed on an informed consent form and filled out a demographic survey. Next the participant was assigned to W3D, S3D, or placebo condition based on a random sequence generated by Microsoft Excel. This sequence was hidden from the experimenters' view prior to participant assignment. In the following experiment, one experimenter verbally guided the participant according to a script and the other experimenter operated a laptop and a TV. The participant controlled proceeding pace of the experiment by pressing "Enter" to play every video clip. Upon completion of the task, the participant filled out a post-experimental questionnaire measuring perceptions of enjoyment, flow, and presence. Finally, the participant was debriefed and thanked.

### Data analysis

SPSS 20.0 was used to perform preliminary and main analyses. The preliminary analysis included (a) the validation of the decision-making task by comparing participants' response accuracy to the chance level (i.e. 50%) using a two-sided *t* test, (b) the calculation of observed alpha coefficients of subjective measures, and (c) examination of statistical assumption violations in the main analysis. The main analysis was a 3 (experimental condition: S3D, W3D, placebo) × 3 (skill-level: varsity, club, recreational) MANOVA on five outcomes, including response accuracy, RT, enjoyment, flow, and presence. Pillai's trace ( $V_{\text{Pillai}}$ ) was used due to its robustness and increased power compared to other statistics (Sheehan-Holt, 1998). *Post hoc* analyses were conducted using least significant difference (LSD) and Cohen's *d*s were calculated for significant results. The alpha level was set at .05.

## Results

### Preliminary analysis

Response accuracy of all the nine groups (3 skill-levels by 3 experimental conditions) was compared to 50%. Recreational did not perform significantly better than chance regardless of conditions,  $t(10) = 1.38$ ,  $p = .19$ ,  $t(8) = -0.11$ ,  $p = .91$ ,  $t(8) = 0.36$ ,  $p = .73$ , for W3D, S3D, and placebo, respectively. Club responded significantly better than chance only in W3D,  $t(12) = 2.94$ ,  $p = .01$ , but not in placebo,  $t(11) = 0.64$ ,  $p = .54$ , or S3D,  $t(12) = 1.12$ ,  $p = .28$ . Finally, varsity performed significantly better than chance in all the conditions,  $t(11) = 5.50$ ,  $p < .001$ ,  $t(12) = 2.34$ ,  $p = .04$ ,  $t(10) = 3.43$ ,  $p = .01$ , for W3D, S3D, and placebo conditions,

respectively (Figure 1(a)). The result pattern supported the validity of the decision-making task. The observed alpha coefficients were .92 (enjoyment), .94 (flow), and .87 (presence), indicating good reliability (George & Mallery, 2003). No assumption violations of MANOVA were identified.

*Main analysis*

The multivariate test of MANOVA revealed a significant skill-level effect,  $V_{Pillai} = .33$ ,  $F(10, 182) = 3.62$ ,  $p < .001$ ,  $\eta_p^2 = .17$ , and a significant experimental condition effect,  $V_{Pillai} = .19$ ,  $F(10, 182) = 1.92$ ,  $p < .05$ ,  $\eta_p^2 = .10$ . However, the skill-level by experimental condition interaction was not significant,  $V_{Pillai} = .08$ ,  $F(20, 372) = 0.39$ ,  $p = .99$ .

*Decision-making outcomes.* The univariate ANOVA for response accuracy identified a significant skill-level effect,  $F(2, 94) = 5.47$ ,  $p = .01$ ,  $\eta_p^2 = .10$ . Varsity ( $M = 61.49\%$ ,  $SD = 11.01$ ) responded significantly more accurately than club ( $M = 55.66\%$ ,  $SD = 13.02$ ),  $p = .04$ , Cohen's  $d = 0.48$ , and recreational ( $M = 52.16\%$ ,  $SD = 12.19$ ),  $p = .002$ , Cohen's  $d = 0.80$  (Figure 2(a)). Additionally, the ANOVA

revealed a significant experimental condition effect on response accuracy,  $F(2, 94) = 3.52$ ,  $p = .03$ ,  $\eta_p^2 = .07$ . Specifically, W3D participants showed significantly more accurate responses ( $M = 60.83\%$ ,  $SD = 12.46$ ) than S3D counterparts ( $M = 53.86\%$ ,  $SD = 12.36$ ),  $p = .02$ , Cohen's  $d = 0.56$ , and trended towards showing significantly more accurate responses than those of the placebo condition ( $M = 55.38\%$ ,  $SD = 12.12$ ),  $p = .06$ , Cohen's  $d = 0.44$

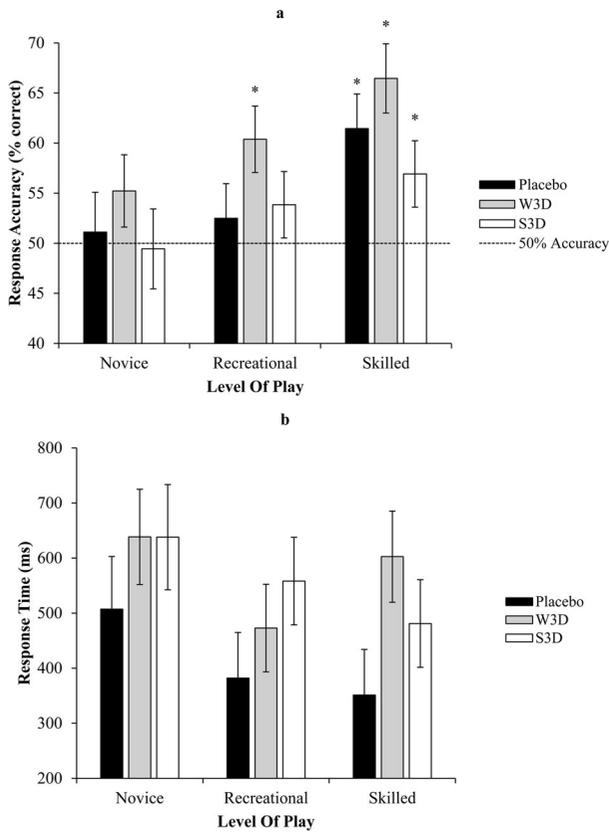


Figure 1. Means and standard errors for response characteristics (accuracy and RT) for novice, recreational, and skilled players by experimental condition. For panel (a), the comparison to the 50% chance level is represented ( $*p < .05$ ).

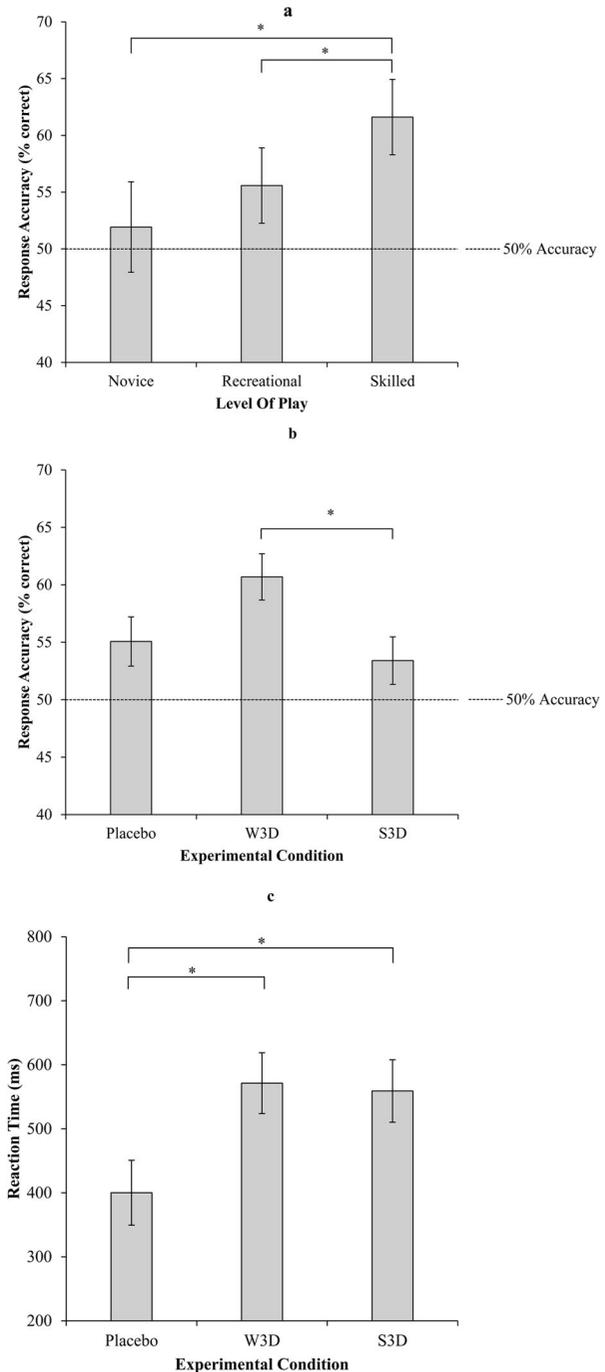


Figure 2. Means and standard error for the main effects of skill-level and experimental condition ( $*p < .05$ ).

(Figure 2(b)). Lastly, the skill-level by experimental condition interaction was non-significant,  $F(4, 94) = 0.24, p = .92$ .

Similar to response accuracy, group differences in RT were tested by a univariate ANOVA. The test showed a significant experimental condition effect on RT,  $F(2, 94) = 3.69, p = .03, \eta_p^2 = .07$ . Placebo participants ( $M = 405.03$  ms,  $SD = 276.11$ ) responded faster than S3D ( $M = 550.0$  ms,  $SD = 272.19$ ),  $p = .03$ , Cohen's  $d = -0.53$ , and W3D participants ( $M = 566.69$  ms,  $SD = 307.48$ ),  $p = .01$ , Cohen's  $d = -0.55$  (Figure 2c). However, neither the main effect of skill-level,  $F(2, 94) = 2.05, p = .13$ , nor the skill-level by experimental condition interaction,  $F(4, 94) = 0.56, p = .69$ , was significant (Figure 1(b)).

*Subjective measures.* The univariate ANOVA for enjoyment indicated a significant skill-level effect,  $F(2, 94) = 3.38, p = .04, \eta_p^2 = .07$ . Pairwise comparison suggested that varsity ( $M = 8.37, SD = 1.93$ ) perceived significantly higher enjoyment during the decision-making task than recreational ( $M = 7.18, SD = 2.10$ ),  $p = .01$ , Cohen's  $d = 0.59$ , and club ( $M = 8.02, SD = 1.88$ ) trended towards perceiving higher enjoyment than recreational,  $p = .09$ , Cohen's  $d = 0.42$ . However, neither experimental condition,  $F(2, 94) = 1.32, p = .27$ , nor skill-level by condition interaction,  $F(4, 94) = 0.57, p = .69$ , resulted in a significant effect.

The univariate ANOVA for flow revealed non-significant effects for either skill-level,  $F(2, 94) = 0.55, p = .58$ , experimental condition,  $F(2, 94) = 2.06, p = .13$ , or skill-level by experimental condition interaction,  $F(4, 94) = 0.39, p = .82$ . Nonetheless, the univariate ANOVA for presence revealed a skill-level effect at a marginal significance level,  $F(2, 94) = 2.79, p = .07, \eta_p^2 = .06$ . Pairwise comparison indicated that club ( $M = 4.39, SD = 1.16$ ) perceived stronger presence than recreational ( $M = 3.68, SD = 1.14$ ),  $p = .02$ , Cohen's  $d = 0.62$ ; however, varsity ( $M = 4.14, SD = 1.37$ ) did not perceive significantly stronger presence than recreational,  $p = .15$ , Cohen's  $d = 0.37$ . Neither experimental condition,  $F(2, 94) = 0.93, p = .40$ , nor skill-level by experimental condition interaction,  $F(4, 94) = 0.11, p = .99$ , resulted in a significant effect.

## Discussion

We followed the human performance model to evaluate whether video stimuli presented using 3D technology enhanced tennis players' decision-making in a temporal occlusion task. In general, we expected a positive impact of 3D technology on both decision-making outcomes and subjective experiences. Several findings ensued. First, varsity players

demonstrated better decision-making (i.e. higher accuracy) than club and recreational players in judging the direction of tennis serve. Second, wearing the passive 3D glasses led to a placebo effect on RT, placebo participants responding faster than those of W3D and S3D. Third, opposite to our prediction, applying 3D technology to W3D video presentation reduced tennis players' accuracy in the decision-making task. Lastly, the subjective measures generated supplemental evidence for understanding previous findings on decision-making outcomes but none supported that 3D technology increased fidelity of the present task.

Given the long-standing observation that experts make more accurate decisions in domain-specific tasks, the finding that varsity players displayed higher decision-making accuracy than club and recreational players irrespective of visual display conditions is unsurprising. Nevertheless, the finding is still meaningful in validating the task that carries new features other than 3D technology. For example, tennis players of both genders responded to video scenarios made with one female and one male server. In addition, the male server is left-handed. Therefore, the current finding implies that expertise effect in our tennis task might be generalizable to less frequent server characteristics such as opposite-gender and left-handedness (Jackson & Mogan, 2007). Subjective measures showed varsity players (and seemingly club players) perceived more enjoyment during the task than recreational players. Such a perceptual difference across expertise levels suggests that experts may have more positive subjective experience during domain-specific tasks while showing better task performance than non-experts. However, with the absence of an expertise effect on flow, such a positive experience of experts is limited to single emotions but not extendable to holistic experience.

The current study also revealed a placebo effect of wearing passive 3D glasses that shortened participants' RT on the task. The placebo effect may help interpret the shared finding of Hohmann et al. (2016) and Lee et al. (2013) concerning the elevated time-efficiency of decision-making in absence of a response accuracy increment. Comparatively, but outside sports context, Read and Bohr (2014) reported a negative placebo effect in a S3D study of movie-watching using a heterogeneous sample (i.e. participant's age ranges from 4 to 82). In particular, about 8% of placebo group participants reported unpleasant perception (e.g. dizziness) after watching W3D movie with 3D glasses. The different placebo effects between sport and movie-watching S3D studies suggests that the specific effect from wearing 3D glasses might depend on task and sample

characteristics. In sport tasks, wearing 3D glasses seems beneficial without arousing negative perceptions. To further understand this placebo effect, future S3D studies in sport are encouraged to include a placebo condition (in addition to W3D and S3D) and measure participants' expectation associated with wearing 3D glasses.

It is unclear why the addition of 3D technology to video presentation decreased participants' decision-making accuracy. It may result from technical shortcomings of 3D technology. For instance, the accommodation–convergence conflict is still an unsolved issue in 3D technology resulting in motion sickness symptoms (Reichelt, Häussler, Fütterer, & Leister, 2010). However, we argue against this technical account because S3D participants did not perceive less enjoyment than those of W3D and placebo and none reported discomfort. Neither do we support the consideration of any negative impact (e.g. darker video display) from wearing the 3D glasses given the favourable placebo effect discussed earlier. Another explanation is that W3D may have an advantage over S3D regarding participants' being more familiar to W3D. Although S3D video is accessible for collegiate population and all the tennis players confirm to have prior S3D experience, it is a different S3D situation for tennis players when they perform the current task than watching S3D movies. Furthermore, the wide record keeping of W3D video clips in tennis makes this explanation look appealing. One way to equalize familiarity between W3D and S3D in sport is to offer training to participants before testing them. Preliminary evidence from training design shows that female handball athletes made better decisions following S3D training than did those following W3D training (Hohmann et al., 2016). However, because Hohmann et al.'s participants were not randomized, future training studies should overcome this limitation.

Related to the familiarity explanation, the performance drop in S3D may reflect a less-than-ideal match between 3D technology and the current decision-making task. This suboptimal match includes at least two facets. First, by expecting S3D to enhance decision-making, we implicitly assumed that the depth cues of the server–racket area are critical for judging the serve direction and that binocular depth cues contributes substantially to depth cue perception beyond W3D. However, these assumptions can be challenged. For example, arguments exist that most cues for human depth perception are monocular (Howard & Rogers, 2012), and that the importance of depth perception from binocular disparity declines quickly when viewing distance increases (Hillis, Watt, Landy, & Banks, 2004). Second, S3D may have disproportionately elevated the saliency of

task-irrelevant cues. In the video scene, the size of task-relevant regions (i.e. arm–racket area) tends to be smaller than some task-irrelevant features (e.g. the net). Because 3D technology enhances cue saliency of near (and thus relatively large) objects (Häkkinen, Kawai, Takatalo, Mitsuya, & Nyman, 2010), those large but task-irrelevant features will get reinforced relative to the arm–racket area. Preliminary evidence from sport studies tracking participants' gaze behaviour suggests that participants tend to fixate on task-irrelevant regions in S3D condition compared to W3D condition (Lee et al., 2013). We thereby recommend future S3D–W3D studies to follow Lee et al.'s technical solution of accommodating 3D glasses with eye-tracker so that participants' gaze behaviour can be recorded throughout task performance.

We have not verified the hypothesis of a manifested expertise effect in a sport task of enhanced fidelity. Although the expert–novice difference was evident, no evidence (presence in particular) supported that S3D has higher fidelity than W3D in the present study.<sup>4</sup> However, testing 3D technology in sport research represents only one pursuit on improving the ecological validity. An ideal situation is to develop a laboratory VE where all the factors from a field task are recreated. From this perspective, 3D technology alone is likely to be limited. We therefore attribute the null result of the subjective measures to the fact that S3D enhances only visual (but not other) perception of participants compared to W3D. Gibson (1966) classified five perceptual systems of human beings, including visual, auditory, haptic, taste-smell, and basic body orienting/balancing system. Steuer (1992) argued that a VE's simultaneous activation of multiple perceptual systems is crucial for the VE perception by reducing the number of alternative situations with the same perceptual feature. Responding to S3D serves in the present study seems more similar to responding to W3D serves in a laboratory than to returning tennis serves on court. This is because our participants were not wearing tennis gear while orienting their bodies in a court-looking space with rackets in hands. This may cause participants to persist in perceiving the immediate physical environment rather than the intended VE. Therefore, we encourage future researchers to explore VE technologies that can simultaneously affect multiple perceptual systems, such as the CAVE system and the “4D film” of theme park attractions.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes

1. We preferred the term “presence” to the term “telepresence” from Steuer (1992) to keep the labeling simple and to maintain coherence between the construct and its measurement tool (Slater, Usoh, & Steed, 1995).
2. The interaxial separation of the 3D camera is 20 mm, smaller than the inter-pupillary distance of targeted testing population. It generated a reduced stereoscopic effect (i.e. hypo-stereo) of our S3D footage. We admit this as a limitation of the current study.
3. For example, one item stated, “How much did you enjoy the tennis simulation?”
4. The finding that club players reported stronger presence during the task than recreational players is possibly confounded by the data collection process. In order to recruit club players during their organized group gatherings, some data collection of this group was moved to a room in the tennis complex where the experimental tennis serves were filmed. Additionally, both tennis gatherings (during which tennis activities are expected) and tennis serve scenarios were at night. Therefore, a substantial proportion of club participants are likely to experience enhanced presence perception because they viewed identical details of the tennis court in both club gatherings and the tennis video clips. For this reason, we assume that club players’ presence perception increment comes from the data collection process.

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