PERCEPTUAL ASSESSMENT OF TENNIS BALL FLIGHT IN A CAVE SYSTEM

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A Cave Automatic Virtual Environment, which is a computer-simulated 3D virtual reality system, is expected to provide sport learners with interactive and immersive learning material. Biomechanical measurements help to construct a simulated sport situation. The purposes of this study were to reconstruct a tennis ball flight in the system, and to assess perceptual impressions and performance of this system. The result of a questionnaire test suggests that the appropriate disparity setting induces a favourable visual impression. A shot type discrimination test (flat, topspin and slice) showed that the four-screen condition was more likely to induce a correct response than one-screen. An appropriate disparity setting with a four-screen immersive environment can provide a realistic tennis situation in a computer-simulated environment.

KEY WORDS: tennis, CAVE, ball flight, perceptual assessment.

INTRODUCTION:

There are a variety of sport-learning materials such as books and videos, but most interactive or hands-on learning has been limited to real-world field practice. Computer-simulated virtual reality (VR), however, can construct an *in-room* interactive and immersive learning environment based on computer graphics (CG) techniques. A Cave Automatic Virtual Environment (CAVE) system used with 3D and immersive virtual reality equipment (Cruz-Neira *et al*., 1992) will provide sport practitioners with hands-on sport-learning materials. Biomechanical motion measurement techniques assist in constructing a sport VR environment. Zaal & Michaels (2003) studied the ball catching performance in CAVE and showed that the way of the ball interception was similar to that in real world.

Tennis is an interactive sport that is immersive and that involves opponents. In a tennis rally, we experience several types of ground stroke, e.g. flat, topspin or slice, so we should learn the shot properties of each type of ball flight in order to apply anticipatory judgement to the shot (Shim *et al*., 2006). CAVE can be an effective tool to help with such training but the reality of the displayed image will have a great influence on the perceptual performance and, eventually, on learning effect. Perceptual assessments are required to use this system practically, thus the aims of this pilot study were as follows: first, to construct a test environment displaying the tennis ball flight in CAVE based on the actual measured value of the trajectory in the field; second, to assess the perceptual impressions and performance of this system. For the former aim, we measured the ball trajectory with a direct linear transformation (DLT, Abdel-Aziz & Karara, 1971) method and used related CG modelling software. For the latter, we conducted two perceptual assessments: a questionnaire test on visual impressions of the displayed image, and a discrimination test of the type of shot in the four-screen and one-screen displays.

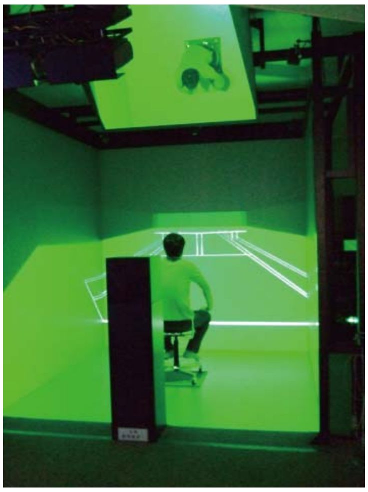

Figure 1: Test CAVE.

METHOD:

Test environment: Two processes were involved in reconstructing the tennis environment in CAVE: Step 1, to measure the ball trajectory on the tennis court; Step 2, to create CG images of the tennis court environment and ball flight animation obtained in Step 1 and then set a test animation in CAVE.

Step 1: A tennis player (age: 23 yr., experience: 10 yr.) was instructed to hit three types of ground stroke, i.e. forehand flat, forehand topspin and backhand slice, aiming at a 1 m x 1 m target area set at the singles right-hand corner of the ball-feeder's side. The ground strokes were videotaped using two synchronized high-speed cameras (HSV-500C^3, nac Inc., Tokyo) operating at a 250 Hz sampling rate. The control area covered the singles tennis court X = 8.23 (m) and Y = 23.8 (m) in horizontal surface, and Z = 2.50 (m) in height. The ball position on the film was digitized on motion analysis software (Frame-DIAS II, DKH Inc., Tokyo), and the DLT method output the 3D coordinate data of the ball flight. The reconstruction standard errors were X = 0.036 (m), Y = 0.054 (m), Z = 0.017 (m), respectively. Digitized frames were selected at the events of the ball-racket contact of the feeder, ball-ground contact of the delivered ball, ball-racket contact of the demonstrator, first ball-ground contact of the shot and the last visible frame, and quartered timing between these consecutive events.

Step 2: A typical tennis court setup was reconstructed on 3D graphics software (3ds Max, Autodesk Inc., San Rafael, CA) and the discrete 3D coordinate data of the ball flight were also imported to the software. The number of digitized frames was approximated from the original 250 Hz data to 30 Hz so it could be displayed in CAVE. The ball flight data were interpolated on a function of key frame animation in 3ds Max. The animation model produced was imported to VR constructing software (OmegaSpace, Solidray Inc., Yokohama, Japan). The viewpoint was set at a position 3 m behind the baseline center on the opposing side of the court to the demonstrator. Our CAVE system has four screens (front, right, left and bottom) and each screen is 2.5 m x 2.5 m in size (Fig. 1). The viewer wore stereo glasses and took a position on the center of the bottom screen.

Experiment 1: Twelve recreational tennis players ($M \pm SD$: age = 22.0 ± 4.0 yr.; experience = 8.2 ± 4.1 yr.) participated in the experiment after giving informed consent to Experiments 1 and 2. They viewed three types of visual stimuli: D0, D1 and D2, in which the disparity (image difference of left and right eye) value of OmegaSpace was set at 0, 0.064 (default) and 0.128, respectively, and each stimulus had three identical items of ball flight data among the stimuli. The experiment was arranged as a randomized complete block design with two replicates. After viewing each stimulus, the participants answered a six-item questionnaire by moving a 0-100 scale slider bar presented on the computer screen. The items were concerned with the visual impression of the displayed tennis ball, namely the appearance of three-dimensionality; appearance of speed; reality of distance; reality of flight trajectory; discomfort; and total VR quality. A within-subject one-way ANOVA was performed to test the disparity effect on the visual impression (alpha = 0.05).

Experiment 2: Six recreational tennis players (age = 21.4 ± 3.6 yr.; experience = 7.3 ± 4.5 yr.), who viewed the visual stimuli displayed only on the front screen of CAVE, were assigned to the S1 group. The other six recreational tennis players (age = 22.2 ± 4.4 yr.; experience = 8.8 ± 4.1 yr.), who viewed the normal CAVE screens (front, right, left and bottom), formed the S4 group. The visual stimuli consisted of nine ground stroke CG animations: three flats, three topspins and three slices. The participants were asked to discriminate the type of shot (flat, topspin or slice) after each stimulus stopped playing. There was no pre-test information on whether the shot was forehand or backhand. The percentage of correct responses (PCR) was compared between the two groups using a Student's t-test (alpha = 0.05).

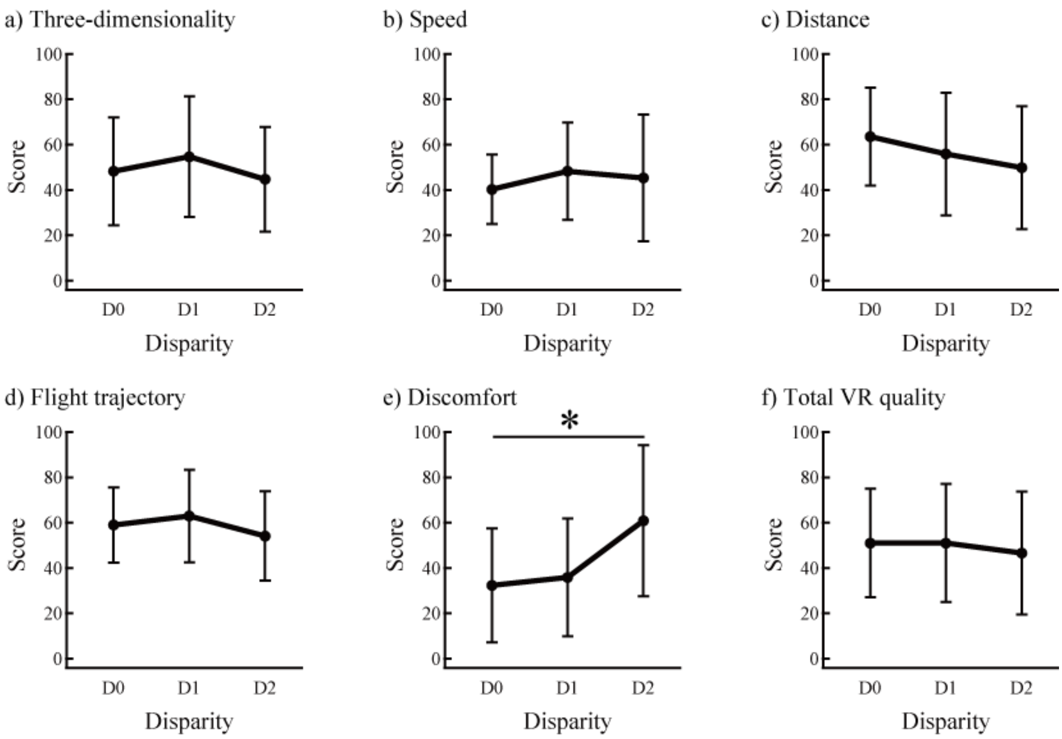

Figure 2: Score of visual impression questionnaire. * $p < 0.05$.

RESULTS and DISCUSSION:

Experiment 1: The result of the visual impression questionnaire is shown in Figure 2. There were no significant differences among the disparity conditions in three-dimensionality, $F(2,35) = 0.94$, $p = 0.41$; speed, $F(2,35) = 0.56$, $p = 0.58$; distance, $F(2,35) = 1.21$, $p = 0.32$; flight trajectory, $F(2,35) = 0.72$, $p = 0.50$; and total VR quality, $F(2,35) = 0.16$, $p = 0.85$, respectively. The sense of discomfort, however, showed significant differences between the D0 and D2 conditions, $F(2,35) = 4.44$, $p < 0.05$.

D2 disparity induced a higher sense of discomfort than D0 did, but the D1 disparity did not show a remarkable increase from D0 on average. To reduce viewer discomfort at this setting, the disparity value should be around or lower than that of the D1 default setting. The senses of three-dimensionality, speed and flight trajectory did not show any significant differences among the disparity conditions, but all of them had the highest mean score at the D1 condition. The sense of distance, however, was the best at the D0 condition on average. The results suggest that the D0 and D1 conditions have both advantages and disadvantages in terms of inducing a realistic sensation of the tennis ball flight. The result of total VR quality supports this because the mean scores of D0 (51.1 ± 24.0) and D1 (51.0 ± 26.0) were shown likely to be equal.

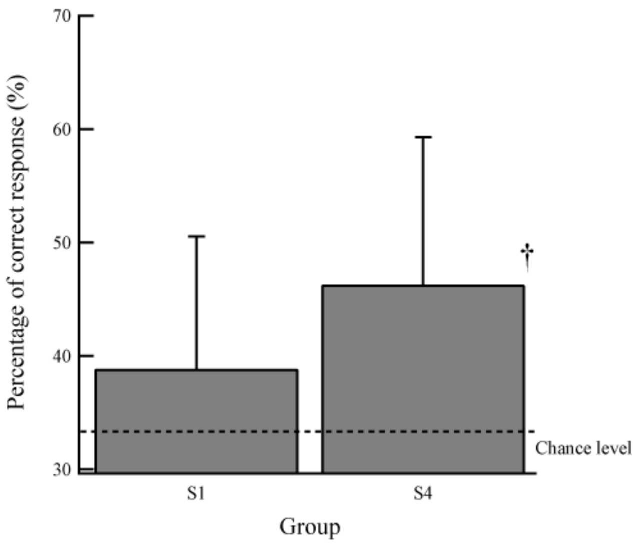

Figure 3: Percentage of correct responses in shot discrimination test. † $p < 0.05$, above chance level.

Experiment 2: The result of the shot discrimination test is shown in Figure 3. The S1 group (38.9 ± 11.7%) failed to discriminate significantly above chance level (33%). On the other hand, the S4 group (46.2 ± 13.0%) performed at a level significantly above chance. However, there was no significant difference between the S1 and S4 groups, $t(10) = 1.05$, $p = 0.32$.
Since the first ball-ground contact of all the nine shots occurred around the edge of the front and right screen, the S4 group obviously had an advantage in using information after the bounce. Thus, it is reasonable that only the S4 group performed significantly above chance level and their mean PCR was higher than that of S1. Although the viewpoint of the current setting had a considerably more posterior location (3 m behind the baseline) than the tennis player's normal position, the ball flight path, particularly after the first bounce, was not completely displayed within the front screen. The side screen is necessary not only to immerse a viewer but also to provide him/her with enough information about the full ball flight.

CONCLUSION:

This study aimed to construct a VR tennis environment in CAVE and assess the perceptual responses of tennis players. We conducted two processes to reconstruct a simulated tennis ball flight: first, the actual ball trajectory was measured by using the DLT method; second, a VR environment was constructed in CAVE based on the actual measured value of the tennis court and ball flight. The questionnaire test revealed that the default disparity setting (0.064) of OmegaSpace output a positive result for the sense of visual impression. The shot discrimination test also revealed that the four-screen (immersive) condition was likely to induce a higher performance from the viewer than one-screen. An appropriate level of disparity setting in combination with a four-screen immersive environment can work better to provide sport practitioners with a realistic tennis situation in VR.

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