Proceedings

Utilizing Virtual Reality to Understand Athletic Performance and Underlying Sensorimotor Processing †

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† Presented at the 12th Conference of the International Sports Engineering Association, Brisbane, Queensland, Australia, 26–29 March 2018.

Published: 12 February 2018

Abstract: In behavioral sports sciences, knowledge of athletic performance and underlying sensorimotor processing remains limited, because most data is obtained in the laboratory. In laboratory experiments we can strictly control the measurement conditions, but the action we can target may be limited and differ from actual sporting action. Thus, the obtained data is potentially unrealistic. We propose using virtual reality (VR) technology to compensate for the lack of actual reality. We have developed a head mounted display (HMD)-based VR system for application to baseball batting where the user can experience hitting a pitch in a virtual baseball stadium. The batter and the bat movements are measured using nine-axis inertial sensors attached to various parts of the body and bat, and they are represented by a virtual avatar in real time. The pitched balls are depicted by computer graphics based on previously recorded ball trajectories and are thrown in time with the motion of a pitcher avatar based on simultaneously recorded motion capture data. The ball bounces depending on its interaction with the bat. In a preliminary measurement where the VR system was combined with measurement equipment we found some differences between the behavioral and physiological data (i.e., the body movements and respiration) of experts and beginners and between the types of pitches during virtual batting. This VR system with a sufficiently real visual experience will provide novel findings as regards athletic performance that were formerly hard to obtain and allow us to elucidate their sensorimotor processing in detail.

Keywords: batting; timing control; head mounted display (HMD); inertial sensor

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1. Introduction

If athletes are to win, they require general abilities related to sports performance, namely fitness, skill and mind. Fitness includes muscle strength, cardiorespiratory function and robustness against injury. This is the main target of conventional sports science, and many findings have been used in various ways in sports coaching and training. Skill and mind are also critical in terms of success in sports, and include coordinating the multiple parts of the body, adequately recognizing a given situation, and overcoming mental pressure. These abilities are mainly determined by sensorimotor processing in the brain. However, the mechanisms involved and the relationship to performance are poorly understood, because work in this area faces a number of technical limitations in a real sports scenario. Thus, most data is obtained in the laboratory. In laboratory experiments we can strictly control the measurement conditions and capture various behavioral and biological data. However, the target action may be limited and differ from actual sports action, and so the obtained data is potentially unrealistic.

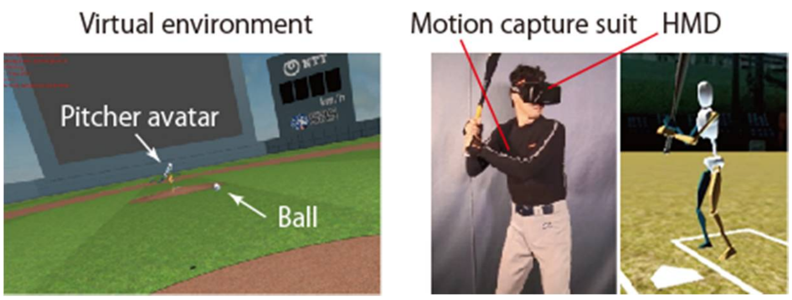
Virtual reality (VR) has the advantage of providing a highly realistic experience. Recently, various virtual reality applications have been developed for use in sports in combination with a highly immersive head-mounted display (HMD), and they have successfully elicited a user's response in a realistic sports scenario [1]. Furthermore, VR has the advantage that it allows us to arbitrarily manipulate a visual environment combined with computer graphics (CG), which makes it possible to configure a visual situation that is inconceivable in the real world.

Using these advantages of VR technology as a basis, we are trying to construct a VR environment for application to baseball and softball batting. This novel VR system can compensate for a potentially unrealistic laboratory situation and obtain sports performance data with a sufficiently realistic visual experience to examine the underlying athletic sensorimotor processing.

2. Materials and Methods

2.1. Virtual Reality System for Baseball and Softball Batting

We have developed an HMD-based VR system for baseball and softball batting in which a user can experience hitting a thrown ball in a virtual baseball stadium entirely constructed from CG using Unity software (Figure 1a). Visual images presented to the batter's right and left eyes are displayed independently on the HMD (Oculus Rift, Oculus or VIVE, HTC) in tune with the position and direction of the user's head at a refresh rate of 90 Hz. This allows the user to obtain a virtual view with appropriate depth sensation for an arbitrary location and orientation in the batter's box. The pitched balls are depicted based on previously recorded ball trajectories, and are thrown in time with the simultaneously measured movement of the pitcher. The ball trajectory is calculated based on a 3D construction obtained using two recorded videos. The pitcher's movement is measured using nine-axis inertial sensors attached to various parts of the body suit (MVN BIOTECH, Xsens) and depicted as a virtual pitcher avatar. The batter and the bat movements are also measured precisely using the same inertial sensor suit, and represented as a virtual batter and bat in real time (Figure 1b). However, while the inertial sensor suit provides rich kinematic data, it can impose a burden on the batters and interfere with their natural action. Alternatively, in the present experiment as stated below, the movements of the batter and bat were simply measured using a single wireless nine-axis inertial sensor (LP-WSD1101-0A, LOGICAL PRODUCT) and an HMD-associated tracker, respectively, in which no virtual batter is presented. To achieve highly realistic batting in real time, we implanted an algorithm in the software to predict the timing of the ball's impact and its location in relation to the bat to compensate for the system delay of bat representation in our virtual space (approximately 100 ms for a whole body sensor system and 11 ms for a few sensors). These VR system settings enable a user to experience a strong feeling of reality, as if standing in the batter's box, and to perform virtual batting in which the ball bounces depending on its interaction with the bat. We can combine the VR system with several measurements, such as muscle activity and respiration, to capture biological information related to athletic performance.



(**a**) (**b**)

Figure 1. (**a**) Right batter's view of virtual baseball environment; (**b**) VR system settings and a virtual avatar described in real time.

Figure 2 shows examples of behavioral responses to virtual batting by a single expert and a beginner using a combination of the Oculus Rift HMD and the whole body sensor system [2]. The participants were instructed to hit fast balls or curve balls that were strikes. This figure shows the head and foot movements and the respiratory waveforms for each of 10 trials that involved randomly presenting fast balls that were strikes. The head movement of the expert participant changed smoothly before the pitcher released the ball, while this was not the case with the beginner. This suggests that the expert prepares in anticipation of the ball's release, while the beginner reacts to the ball's release. The expert also synchronized his respiration, and moved his front foot, while estimating the timing of the ball's impact. These indicate certain features of athletic behavior in a realistic batting scenario that would not be easy to capture in a real game.

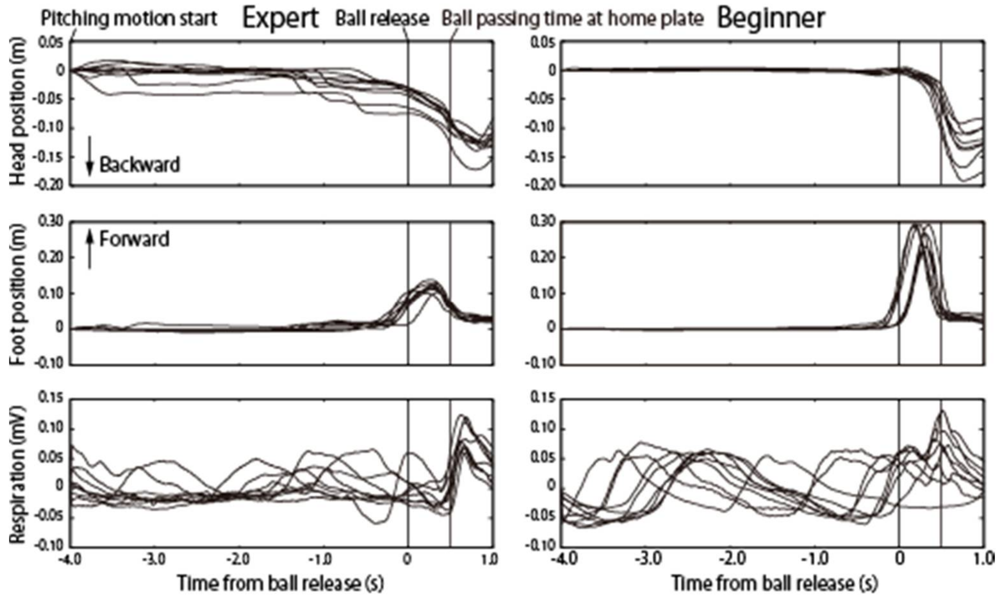
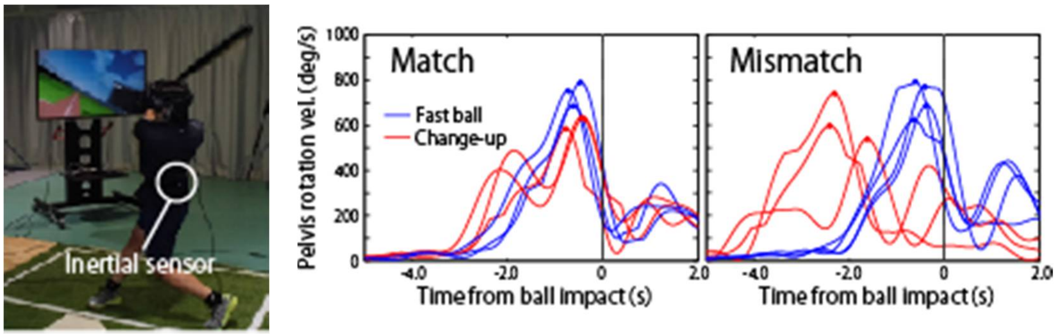


Figure 2. Examples of movement and respiration waveforms during fastballs with strikes in virtual baseball batting in an expert and a beginner [2].

2.2. Virtual Batting Experiment

Previously we found that skillful female softball players adjust the timing of the bat swing motion of the whole body to the ball impact according to the ball speed when the pitcher randomly throws change-up (slow) balls or fast balls [3]. Their swing starts diverged depending on the pitch types by about 300 ms from the time the pitcher released the ball so that the peak timing of the sum of all the body velocities was almost constant just before the ball impact regardless of the pitch types. This suggests that expert batters make very early decisions about swing timing based on information related to the pitcher's motion as well as ball trajectory just after the pitcher releases the ball. In this experiment, we manipulated the pitcher's motion using the VR system to assess its effect on the batting timing control.

Five elite female softball players were instructed to hit a pitched ball in a virtual softball environment (Figure 3a). A pitcher avatar randomly threw change-up or fast balls with different ball speeds and trajectories. In the early part of the experiment the pitcher's motion and ball type (change-up or fast ball) were matched correctly (each of eight trials, Match condition). On the other hand, there was a mismatch (e.g., fast ball motion and change-up ball, Mismatch condition) in the later part of experiment. However, we did not inform the participants that there were two different conditions. Before the test, several practice trials were performed for each ball condition in which information about the type of pitch was presented beforehand in virtual space.



(**a**) (**b**)

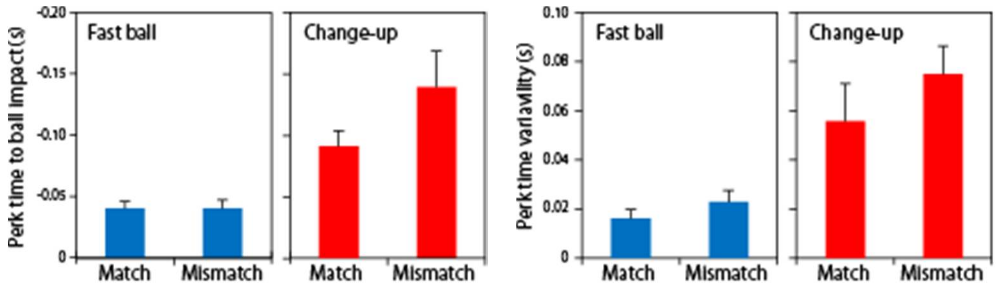
Figure 3. (**a**) Experimental scenery; (**b**) Examples of the pelvis rotation velocity profiles aligned at the ball impact in a single participant. Each dot shows the detected peak of rotation velocity in each trial.

Our recent study showed that key features of bat swing motion were simply detected from the motion of the pelvis using a single wireless nine-axis inertial sensor attached to the lumber region [4]. We found that the timing of the pelvis rotation of an expert softball batter is regulated according to the ball speed, which was almost the same as that of the whole body motion. Therefore, in this experiment, the batter's behavior was measured using the same wireless inertial sensor at a sampling rate of 90 Hz. Participants used an HTC VIVE HMD, which displayed virtual space at a refresh rate of 90 Hz. In advance, we measured the motions and ball trajectories of fast balls (approximately 90 km/h) and change-up balls (approximately 75 km/h) with a strike for an elite female softball pitcher, and then implemented four combinations of pitcher avatars and ball trajectories for two ball types in the VR system (two combinations in each ball type that were randomly presented in the experiment). Other settings of the VR system were the same as above. We evaluated the peak time of the pelvis angular velocity to the ball impact for each test trial. The trials in which inertial sensor data was noisy or lost were excluded from further analysis.

3. Results

Each participant could almost hit the pitched balls regardless of the difference in two (Match and Mismatch) conditions, except two trials in two participants, but the temporal patterns of the trunk movements were different between these conditions. Figure 3b shows examples of the squared sum profiles of the pelvis angular (rotation) velocities aligned at the ball impact for a single participant (Blue: fast ball, Red: Change-up ball). In the Match condition, the peak rotation time was almost the same for fast balls and change-up balls, although the pelvis rotation started somewhat earlier with change-up balls. Such behavior is identical to our recent finding for a skillful softball batter in actual batting [4]. This indicates that our VR system has sufficient reality for studying softball batting. On the other hand, the peak time with change-up balls was variable and was earlier in the Mismatch condition. Each participant could almost hit the pitched balls regardless of the difference in the Match and Mismatch conditions, except two trials.

Figure 4 shows the group mean and standard error for the peak time (a) and its variability (b) of the pelvis angular velocities aligned at the ball impact. The mean peak time for change-up balls was faster in the Mismatch condition than in the Match condition, while that for fast balls was nearly the same for the Mismatch and Match conditions. There was the same tendency as regards the peak time variability. Interestingly, no participants were conscious of the mismatches when we informed them about the mismatch trials after the test.



(**a**) (**b**)

Figure 4. (**a**) Group mean of the peak time of the pelvis rotation velocity; (**b**) Group mean of the peak time of the pelvis rotation velocity.

4. Discussion

In this study we found that there was degradation in timing adjustment to a pitched ball during virtual softball batting when the pitcher's motion and ball type (change-up or fast ball) were mismatched, especially as regards fast ball motion and change-up trajectory condition. This result suggests that an expert batter utilizes information related to the pitcher' motion when making a "swing or wait" decision probably related to fast ball-based timing control strategy [5]. Interestingly, no participants were aware of the mismatches. Thus, this cognitive judgement regarding the pitcher's motion would be made in an unconscious manner and contribute to any adjustment of the swing timing. Many studies have suggested the importance to batting information about the pitcher's motion [6,7]. Our result directly supports this suggestion using virtual space.

Baseball and softball batters must hit a thrown ball correctly within very tight time constraints (within about 0.5 s) from the release of the ball by the pitcher to the moment of impact [8]. In this short time the batter has to execute various complicated sensorimotor processes related to batting control, which include predicting and perceiving the behavior of the ball, planning and generating coordinated movements and correcting ongoing swing trajectory. However, it is very hard when investigating a batter's performance to determine whether a process is excellent or poor in real batting. Our finding provides one cognitive feature in the implicit (unconscious) sensorimotor processing of skillful bat control.

5. Conclusions

Our VR system will provide realistic behavioral data under highly controlled experimental conditions. The system will also make it possible to capture data that were formerly hard to observe without potential physical limitations such as manipulating the combination of pitcher's motion and ball trajectory in this study. Furthermore, the combination of our approach with various measurements, such as muscle activity, eye movement and heart rate, should enable us to understand multiple aspects of sports performance such as how force is exerted and lines of sight. We anticipate that our work using VR technology will clarify the key features of an athlete's skill and mental state and the underlying sensorimotor processing by the brain, which have not been determined with existing approaches in the laboratory or in real sports fields.

Conflicts of Interest: The authors declare no conflict of interest.

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