Assessment of the Visual Behavior of Volleyball Players While Blocking the Ball: A Study Using a Wearable Camera

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[Received March 11, 2016; Accepted March 1, 2017; Published online May 16, 2017]

The present study was conducted to analyze the visual behavior of volleyball players using a wearable camera, instead of the expensive eye trackers that have been employed to date. The position of the player’s forehead, i.e. the direction of the line of sight, was estimated approximately from the images recorded by the camera (pilot studies 1 and 2). We then examined differences in the player’s gaze shift patterns, ball pursuit time and initial spiker fixation when blocking the volleyball, as a function of experience in playing volleyball (main study). The results from pilot studies 1 and 2 indicated that the ball pursuit time from just after release of the ball by the setter and the time taken to fix on the spiker, i.e. the time between the blocker’s eyes leaving the ball and shifting to the spiker, was measured as accurately by the wearable camera as by using an eye tracker. The main study indicated that gaze shift pattern was separable into “gaze shift” (volleyball players, 100% and general sports players, 47.8%) and “ball pursuit” types (general sports players, 52.2%) indicative of skills based differences. However, there was no detectable difference in the time when players shifted their sight from the ball, or in the time when they saw the spiker, according to skills based on prior volleyball experience. In conclusion, the present findings indicate that it is possible to estimate visual behavior during blocking tasks in volleyball using a less expensive wearable camera, rather than an expensive eye tracker.

Keywords: eye tracker, estimation accuracy, field experiments

1. Introduction

Ball play in any sport requires a good ability to collect information, such as the trajectory of the ball and the speed, location, and motion direction of opponents and teammates, to use this information to predict the movement of the ball and players, and on that basis choose and execute one’s own moves (Williams et al., 1994). Selection of appropriate information from the surrounding environment involves visual perception of objects in the correct format (Kato, 2004). Studies of visual tracking have usually relied on the pupil cornea reflection method for accurate measurement of the line of sight (Kato and Fukuda, 2002; Nagano et al., 2004; Naito et al., 2004). This conventional technology has placed limitations on previous studies because of the need to stabilize the head when presenting subjects with videos and pictures of sports panoramas. However, recent eye trackers have become lighter and smaller, making it possible to examine the line of sight while moving the body (Umezaki et al., 2014). Investigation of line of sight of sports players during games would be expected to improve both performance and coaching.

However, use of an eye tracker for the pupil cornea reflection method is an expensive option for collecting visual search information from sport-teams players in the field, and it is difficult to adopt in training. Use of the eye tracker requires time for preparation and calibration, as well as for identifying issues related to practical application of the visual search information to actual coaching, and also there is a need for technical training. Therefore, a device or method that is convenient and less expensive for assessment of visual searching, line of
sight, and field of view would be more valuable for application to sport players in the field.

Recently, so-called wearable cameras, or action cameras, have been used predominantly in the field of extreme sports. These are small, inexpensive cameras worn on the head, and which record video similar to the field-of-view camera of an eye tracker. Installing such a wearable camera on a player’s head and using it as a field-of-view camera is very useful for convenient collection of large amounts of data.

However, no previous studies to investigate line-of-sight measurements in sports have utilized wearable cameras, and therefore their accuracy is unknown. In order to apply line-of-sight information from a wearable camera to skill assessments in sports situations, it is essential to examine the methodology and accuracy. Therefore, the aim of the present study was to analyze visual behavior using a wearable camera instead of an expensive eye tracker. Using images of visual fields that had been recorded using a wearable camera, the position of each individual’s forehead, i.e. the direction of the line of sight, was estimated approximately (pilot studies 1 and 2).

Catching a ball in sports situations requires adequate collection of effective visual information and using it to make estimations and decisions. Therefore, a number of visual search studies have focused on ball-catching. Sports players are generally adept at smooth pursuit of a ball’s trajectory by eye movement, and previous studies have indicated that this is related to estimation of the contact time between the ball and the hand (McBeath et al., 1995; Oudejans et al., 1999). Accordingly, it has been suggested that appropriate viewing of a ball’s trajectory is essential for improvement of performance. However, on many occasions during actual games, players cannot focus solely on the ball. For example, when blocking balls in volleyball, players not only have to visually perceive the ball, but also must simultaneously take account of the spiker’s moves. In a study that has examined visual search activities during volleyball mini games, while the setter tosses the ball and the spiker hits the ball, a player has to visually perceive three objects, i.e. the setter, the ball and the spiker (Umezaki et al., 2014). Volleyball coaches usually instruct players to block the ball while looking at the spiker’s moves, although the effectiveness of this approach has not been evaluated quantitatively in terms of visual searching. When beginners block a ball, it has been predicted that they would watch the ball tossed by the setter for a longer time (ball watchers) in comparison to experienced players. Consequently, the timing involved in watching the spiker would be delayed. Therefore, the level of skill might affect the visual search.

The second purpose of the present study was to quantitatively examine and detect the gaze shift patterns of volleyball players and differences in timing between them as a function of blocking movement skill, reflecting the switching of sight from ball to player in any sport, by examining the accuracy of line-of-sight estimations obtained using a wearable camera (main study).

2. Pilot study 1: Identification of criteria for line-of-sight estimations and examination of their accuracy

2.1. Purpose

The purpose of pilot study 1 was to identify the judgment criteria used for line-of-sight estimations when volleyball players carry out blocking movements, and to examine their accuracy, in a simulated experiment using a wearable camera.

2.2. Methods

2.2.1. Participants and experimental tasks

The participant in pilot study 1 was an adult with normal vision that was better than 1.0 after contact lens correction. The study was approved by the Ethics Committee of the Faculty of Budo & Sports Studies, Tenri University (2013-02). The participant signed a written informed consent form for participation in the study. Two assistants were also involved: assistant A, who acted as a setter for throwing the ball, and assistant B, who acted as a spiker to receive the tossed ball.

As shown in Figure 1(a), assistants A and B stood six meters apart in a straight line, separated by three meters from the participant. In the experiment, assistant A threw the ball with an underhand toss with both hands to assistant B. To maintain consistency of height and timing during the experiment, assistant A practiced throwing the ball so that it stayed within four to five meters from the ground. The
participant was asked to track the movement of the ball thrown by assistant A and to move his eyes to look at assistant B at his own discretion. The participant's visual behavior was recorded at different time points after assistant A had thrown the ball until the ball reached its peak trajectory. A total of 24 trials were conducted. Error trials, in which the line of sight could not be determined due to blinking or the effects of room lighting, were excluded from the analyses. The experiment was conducted in a large indoor classroom.

### 2.2.2. Apparatus

The participant wore an eye tracker (EMR-8b, Nac Image Technology, Tokyo) and a wearable camera (GoproHero3, Gopro. Inc.) on the forehead, and his visual behavior was recorded simultaneously (see Figure 2). Data sampling by the eye tracker was set at 59.94 fps. We calibrated nine fixation points prior to the experiment. The data sampling by the wearable camera was set at 29.97 fps. Prior to the experiment, the participant looked at assistant A, and we confirmed that assistant A was located in the center of the wearable camera screen.

Then, the participant followed the movement of the ball thrown in the air with his eyes in order to adjust the camera angle, such that the ball would be recorded in the center of the screen.

### 2.2.3. Data analysis and identification of judgment criteria for line of sight estimation

We measured the eye movements of the blocker using an eye tracker (EMR-9, Nac Image Technolo-
Figure 3 Specifications of the initial spiker
values estimated from the wearable camera and the actual values obtained from the eye tracker, in order to examine the accuracy of the data.

2.3. Results and discussion

The coefficient of correlation between the actual and estimated values of the proportion of the ball pursuit time interval was 0.99 (actual mean value 30.4, $s = 16.9\%$, estimated mean value 31.8, $s = 16.4\%$), and the initial spiker fixation time interval was 0.95 (actual mean value 50.7, $s = 15.9\%$, estimated mean value 54.3, $s = 13.5\%$), suggesting a high accuracy of estimation. Though limited to the blocker’s visual behavior from tossing to spiking, and when the directions of the head and eyes were identical, the criteria that were identified using the wearable camera were considered valid for estimating the initial gaze shift and spiker fixation times for any individual participant.

3. Pilot study 2: Examination of the effectiveness of line-of-sight estimation

3.1. Purpose

The purpose of pilot study 2 was to examine the effectiveness (accuracy and precision) of criteria for judging line-of-sight estimations obtained in pilot study 1 by recreating the experimental environment that imitated the movement of a ball from toss to spike, by using data from multiple participants.

3.2. Method

3.2.1. Participants and tasks

Three adult men participated in the study. All had normal or corrected vision better than 1.0. The study was approved by the Ethics Committee of the Faculty of Budo & Sports Studies, Tenri University (2013-02). All participants signed written informed consent for participation in the study. Similarly to pilot study 1, two assistants, assistant A who acted as the setter and assistant B who acted as the spiker, also participated. Assistant A had 12 years experience of playing in a volleyball team and six years of coaching experience. The same assistants served in all of the trials.

In study 2, the task of the participants was to gaze at ball movements that were supposedly “tossed from the setter to the spiker”, simulating the gaze shift corresponding to blocking in volleyball games. The experimental apparatus was identical to that of pilot study 1 with one exception: assistant A threw the ball over one meter in the air before the toss, and he tossed the falling ball using an overhead pass to assistant B, who acted as a spiker. Assistant A was trained to ensure that the ball always reached a height of four to five meters from the ground, such that the timing and high consistency of the toss could be maintained at the trials. As in pilot study 1, instructions were given to participants about their visual behavior. Each participant engaged in 30 trials, and any error trials in which the line of sight could not be identified because of eye blinking and the effects of indoor lightning were excluded from the analysis. The experiment was conducted in a gym to create an environment similar to that in an actual volleyball game.

3.2.2. Apparatus

The same apparatus as that in pilot study 1 was used in pilot study 2.

3.2.3. Data analyses

The flight time of the ball from toss impact until when it was caught by assistant B was defined as the “toss time” (ms). The “ball pursuit time interval” (ms) and the “initial spiker fixation time interval” (ms) were calculated using the same method as that in pilot study 1. In order to quantitatively assess the errors of estimation that were made when using the wearable camera, we calculated the measurement error by subtracting the actual value obtained from the eye tracker from the estimated value for each trial. The accuracy index of estimated values for each participant was obtained by calculating the average of the measurement errors. The standard deviations of measurement errors were used as an index of precision. Moreover, for convenience, we calculated the coefficient of correlation between the actual and estimated values for each participant, with the aim of examining the accuracy of the data.

3.3. Results and discussion

Table 1 shows the ball pursuit time interval, the initial spiker fixation time interval, and the toss time obtained from the eye tracker and the wearable
Table 1  Accuracy and precision of the estimated value obtained by the wearable camera.

|               | n  | Measurement values obtained by the eye tracker (ms) | Estimated values obtained by the wearable camera (ms) | Accuracy (ms) | Precision (ms) | Correlation coefficient |
|---------------|----|---------------------------------------------------|------------------------------------------------------|--------------|----------------|------------------------|
| **Ball pursuit time** |    |                                                    |                                                       |              |                |                        |
| ID 1          | 24 | 504.9±191.0                                       | 517.2±189.5                                          | 12.3         | 32.4           | .986                   |
| ID 2          | 22 | 423.5±156.1                                       | 442.9±158.9                                          | 19.4         | 25.9           | .987                   |
| ID 3          | 29 | 459.8±185.5                                       | 447.6±165.8                                          | 12.2         | 36.8           | .984                   |
| **Initial spiker fixation time** |    |                                                    |                                                       |              |                |                        |
| ID 1          | 24 | 860.4±149.2                                       | 877.3±127.3                                          | 16.8         | 56.5           | .929                   |
| ID 2          | 22 | 766.7±205.9                                       | 838.7±146.5                                          | 72.1         | 83.2           | .944                   |
| ID 3          | 29 | 856.1±152.8                                       | 873.3±166.8                                          | 17.0         | 89.1           | .848                   |
| **Toss time** |    |                                                    |                                                       |              |                |                        |
| ID 1          | 24 | 1449.3±57.0                                       | 1461.2±60.6                                          | 11.9         | 16.2           | .964                   |
| ID 2          | 22 | 1487.9±65.5                                       | 1495.4±60.6                                          | 7.6          | 13.3           | .955                   |
| ID 3          | 29 | 1437.4±57.7                                       | 1441.7±60.1                                          | 4.3          | 9.4            | .966                   |

camera for each participant. The accuracy and precision of each time and correlation coefficient are also displayed in the table.

There were no significant differences in toss time for the values obtained from the eye tracker and the wearable camera, indicating that the wearable camera was able to adequately evaluate the time from toss to catch. The data in pilot study 2 were collected at 59.94 fps by using the eye tracker and at 29.97 fps by the wearable camera, since the size of one frame of the eye tracker, which has an error of approximately 17 ms, was the limit of sensitivity for the device. Therefore, it was considered that measurements obtained using the wearable camera were adequate.

The accuracy of the ball pursuit time interval was 12.2-19.4 ms, corresponding to one segment in the video frame at 29.97 fps. Moreover, as the precision, i.e. the standard deviation of the measurement error, was 25.9-36.8 ms, the precision of the estimated value was equal to less than two segments when converted to the size of the video frame. All participants showed a high correlation, \( r = 0.98 \). Therefore, we confirmed that the wearable camera could be used to instantly identify the time that the participants shifted their sights from the ball without using an eye tracker.

On the other hand, the accuracy of the initial spiker fixation time interval was 16.8-72.1 ms, which corresponded to an error of about two segments when converted to the size of the video frame. The precision was 56.5-89.1 ms, indicating an error of within three segments. Two participants (ID1 and ID2) showed a high correlation, \( r = 0.92 \), and one participant (ID3) also showed a relatively high correlation, \( r = 0.84 \), between the actual and estimated values. The accuracy and the precision were higher than those of the ball pursuit time interval. Reviewing the eye mark video from the eye tracker revealed that the participants, when looking at the spiker, often shifted their gaze over the spiker, and then shifted back to the spiker. This could have been a factor in the estimation error. Comparison of the time estimation when the gaze shifts from the ball indicated that the error was larger for estimation of the time when the spiker appeared in the visual field. Although limited to the blocker’s visual behavior from tossing to spiking, and when the directions of the head and eyes were identical, it was considered possible to estimate gaze shift to the spiker using the wearable camera.

4. Main study: Estimation of line of sight when blocking in the volleyball court

4.1. Purpose

The purpose of this study was to quantitatively examine the gaze shift pattern of volleyball players and to detect differences in the time and patterns as applied to actual game situations.

4.2. Methods

4.2.1. Participants and tasks

The participants of this study were 33 male college students of whom 10 were expert volleyball players (volleyball players) and 23 were general
Table 2 Mean ± SD of Age, Height, Body weight, Sports experience under 2 group.

|                      | Volleyball players (n = 10) | General sports players (n = 23) |
|----------------------|-----------------------------|---------------------------------|
| Age (years)          | 19.4 ± 1.0                  | 20.3 ± 0.5*                    |
| Height (cm)          | 177.8 ± 5.6                 | 177.0 ± 7.6                    |
| Body weight (kg)     | 69.4 ± 5.4                  | 72.8 ± 10.1                    |
| Sports experience (years) | 9.6 ± 2.9                 | 10.9 ± 3.5                     |

* Volleyball players vs General sports players (p < .05)

sports players (8 basketball players, 7 soccer players, 6 athletes, 2 baseball players) other than volleyball (general sports players) (see Table 2). The study was approved by the Ethics Committee of the Faculty of Budo & Sports Studies, Tenri University (2013-02). All participants signed written informed consent for participation in the study. Five assistants helped to conduct the experiment: Assistant A acted as a setter, assistant B acted as a receiver that passed the ball to the setter, and assistants C, D and E served as spikers from three different positions: center, left and right (see Figure 1(c)). The five assistants had an average of nine years of volleyball experience and were currently playing in volleyball teams. In order to create an environment identical to that in actual games, the experiment was conducted at a volleyball court in a gym. The height of the net was 2.43 m for the volleyball players and 2.20 m for general sports players.

The participants’ task was to block the attack from three directions. In the experiment, the setter (assistant A) who had received the ball from the receiver (assistant B) tossed the ball to the spikers (assistants C, D, and E) at either center, left or right, and the spiker at that position spiked the ball. The toss for the center was controlled to be a “quick set” (the spiker first makes an approach run and the setter tosses the ball so that its trajectory matches the hitting point). The toss for the left or right was controlled to be a “shoot set” (the spiker adjusts the timing of the approach run to the trajectory of the tossed ball). The setter (assistant A) tossed the ball in random order. The time for the flight of the ball from the toss impact to the spike impact was defined as the “toss time” (ms), which was analyzed. Participants were told to start from the center near the net and move around in the court to block the attack. Participants received an attack from the left in at least 15 trials.

4.2.2. Experimental apparatus and procedure

A wearable camera (Gopro Hero 3, Gopro Inc.) was used to estimate the line of sight. The camera was mounted on the forehead of each participant using a head strap, and recordings were made at 29.97 fps. The calibration of the camera angle was conducted using the same procedure as that in pilot study1.

The video recorded by the wearable camera was analyzed frame-by-frame so that the object in the center of the screen was the visual target. Moreover, based on the previous studies, the time when drastic changes on the screen occurred after the toss was defined as the “initial gaze shift time”, which was the time when the sight shifted from the ball, based on afterimages of lights as criteria for making the judgment.

The mean and standard deviations for each criterion were used as the individual scores, and the differences between the volleyball players and the general sports players were analyzed. The intra-rater reliability of the ball pursuit time interval and initial spiker fixation time interval was assessed using the interclass correlation (ICC) method. The level of significance was defined as less than 5%.

4.3. Results

The intra-rater ICC values were 0.83 (ball pursuit time interval) and 0.60 (initial spiker fixation time interval). We categorized the line of sight pattern based on frame-by-frame analysis of sight estimation, and two types were defined: “the ball pursuit type” in which no gaze shift was observed as the participants followed the ball from toss impact to spike impact, and the “gaze shift type” in which participants shifted the sight to the spiker after pursuing the tossed ball from the setter. All of the volleyball players were of the gaze shift type, whereas 11 (47.8%) of the general sports players were also of this type. Twelve general sports players (52.2%) were categorized as the ball pursuit type.

Table 3 shows a comparison of each variable among the 21 players who were categorized as the gaze shift type. The average proportion of trials in which the participants were able to touch the spiker ball was 8.0% for the general sports players and 38.7% for the volleyball players, the latter being significantly higher.

Examination of the variables associated with the
Table 3  Group comparison of each variable.

|                          | Volleyball players | General sports players | P-value | 95% CI      | ES  |
|--------------------------|--------------------|------------------------|---------|-------------|-----|
| Mean Ball pursuit time   |                    |                        |         |             |     |
| Time (ms)                | 322.3 ± 79.7       | 336.5 ± 113.9          | 0.747   | −76.5~104.9 | 0.08|
| toss time proportion (%) | 23.0 ± 5.8         | 24.0 ± 8.6             | 0.772   | −5.8~7.7    | 0.07|
| Initial spiker fixation  |                    |                        |         |             |     |
| time (ms)                | 559.0 ± 91.7       | 626.0 ± 151.3          | 0.241   | −48.8~182.8 | 0.27|
| toss time proportion (%) | 40.0 ± 6.9         | 44.5 ± 11.6            | 0.300   | −4.3~13.4   | 0.24|
| SD                       |                    |                        |         |             |     |
| Ball pursuit time        |                    |                        |         |             |     |
| Time (ms)                | 43.4 ± 11.1        | 58.2 ± 29.6            | 0.145   | −5.8~35.5   | 0.34|
| toss time proportion (%) | 2.9 ± 8.0          | 4.3 ± 2.2              | 0.076   | −0.2~2.9    | 0.41|
| Initial spiker fixation  |                    |                        |         |             |     |
| time (ms)                | 59.5 ± 17.3        | 71.1 ± 23.1            | 0.212   | −7.2~30.3   | 0.28|
| toss time proportion (%) | 4.0 ± 1.1          | 4.9 ± 1.7              | 0.167   | −0.4~2.2    | 0.31|
| Mean block touch proportion | 31.6 ± 21.4      | 12.7 ± 16.6            | 0.035   | −0.4~0.0    | 0.64|

line of sight location indicated that differences in the mean ball pursuit time interval, in which the average score of 15 trials for each player was used as the individual score, was approximately 15 ms, and did not differ significantly between the groups. On the other hand, the initial spiker fixation time interval for the volleyball players was approximately 70 ms shorter than that for general sports players. Although this proportion was 5% less, the difference was not significant. Next, we used the standard deviations of 15 trials as the individual score in order to evaluate the variability between trials. Although both the ball pursuit and initial spiker fixation time intervals were shorter for the volleyball players, there were no significant inter-group differences.

4.4. Discussion

All of the volleyball players were categorized as the gaze shift type, whereas about half of the general sports players were categorized as the ball pursuit type. Volleyball requires a quick transition of sight from a ball to a player within a relatively small space. In particular, in order to block the ball effectively, it is essential to predict the course of the ball by reading the spiker’s movement. Therefore, shifting the sight from the ball to a player is a skill that is acquired by a volleyball player, and convenient methodology utilized in the present study enabled us to evaluate this skill.

Moreover, our quantitative assessment of gaze shift time indicated that volleyball players had a shorter initial spiker fixation time interval than did general sports players, although the difference was not significant. An eye saccade study conducted with volleyball players and college students indicated that volleyball players shifted their sight more quickly from a receiver to a setter in comparison to college students, when predicting the direction of the tossed ball from the setter (Piras et al., 2010). This suggested that volleyball players had longer fixation times on the setter than did general sports players. This particular gaze strategy is termed the “quiet eye” (Vicker, 1996). In the present study, volleyball players accurately estimated the location of the spiker by quickly recognizing diverse information, such as the speed of the ball, angle, and direction, from toss impact to the initiation of gaze shift. Therefore, they were able to read the spiker’s moves more quickly than general sports players, suggesting possible use of the quiet eye by volleyball players in the present study. However, no difference in skill based on volleyball experience was detected in terms of the time taken for players to shift their sight from the ball, or to see the spiker.

5. Conclusion

In the present study, we identified criteria for line-of-sight estimation in a simulated experiment using a wearable camera by analyzing blocking movements in volleyball (pilot study 1). We then assessed the validity of the criteria we obtained (pilot study 2). Finally, in an experiment using a wearable camera (main study), we examined differ-
ences in gaze shift pattern and timing as a function of volleyball experience in the field. Studies 1 and 2 indicated that the ball pursuit and initial spiker fixation time intervals were measured appropriately by use of the wearable camera. The main study indicated that the gaze shift pattern could be categorized into “gaze shift” (volleyball players, 100%; general sports players, 47.8%) and “ball pursuit” types (general sports players, 52.2%) indicative of skill-based differences. These results indicate that it is possible to estimate visual behavior when conducting blocking tasks in volleyball using less expensive wearable cameras, without the need for expensive eye trackers.

Acknowledgements

The authors wish to thank all participants who took part in the present study. This work was supported by intramural grant of the Tenri University

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Acknowledgements

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Main Works:
• Umezaki, S., Kida, N., and Nomura, T. (2014) Visual search data collection of a volleyball player in a four-on-four game situation. Res. J. Sport Perform., 6: 36-50. (in Japanese with English abstract)
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Membership in Learned Societies
• European College of Sport Science
• Japanese Society of Coaching Studies
• Japan Society of Human Growth and Development
• Japan Society of Physical Education, Health and Sport Sciences
• Japanese Society of Volleyball Research