A Biomechanical Method to Quantify Motion Deviation in the Evaluation of Sports Techniques using the Example of a Basketball Set Shot

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Abstract

The evaluation and diagnosis of the techniques of a client and the identification of technical faults are essential but difficult steps in the optimization loop. The purpose of this paper is to propose a biomechanical method to quantify motion deviation in the evaluation of sports techniques, using the example of a basketball set shot. The motion deviation from a standard motion was quantified by a z score. The idea of using the weighted z score is introduced to demonstrate the importance of the motion deviation. The motion used as a sample was a basketball set shot that was performed by twenty-six female players from a varsity club. Twenty-five segment endpoints were obtained with a VICON 612 system with nine cameras operating at 120Hz. Fifteen segment angles, including elbow and knee joint angles, were calculated in this study, and the coefficient of variance of the segment and joint angles was calculated. The z score was calculated as an index of motion deviation, and the weighted z score was introduced based on the hypothesis that a motion with small *mCV* allows less individual difference in the motion. This is important because most of the subjects performed a similar motion to solve the motion task. The major results obtained were that (1) the *mCV* can be used to detect critical points of sports techniques; (2) the z score can be used to quantify deviations of a specific player from the model technique; and (3) the weighted z score can be used to identify a client's technical faults and correction points.

Key words:standard motion, motion variability, motion deviation, sports techniques.

1. INTRODUCTION

We first observe the performance and motions of subject athletes and then compare their techniques and motions with those of superior athletes as a model for improving and optimizing those techniques. We then evaluate and diagnose the subject athletes' techniques and motions and identify technical faults or limiting factors. Finally, we attempt to teach the athlete to modify his or her technique and motion through appropriate training. Ae et al.[1] proposed a method to provide a standard motion as an averaged motion pattern for skilled performers, which can then be applied to create a motion-pattern template for good sports techniques. Standard motions and motion variability can be used to identify critical points and technical faults.

The essential but most difficult steps in the above optimization loop are the evaluation and diagnosis of the techniques of the client, a student athlete, and the identification of technical faults and limiting factors. Although various methods have been proposed and used to evaluate sports techniques, one of the most frequently used methods is to compare the client's motion with predetermined motion models. After comparison of the sports techniques, the next task for an evidence-based evaluation and diagnosis of sports techniques is to indicate what differences there are between the client's motion and the motion models

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and to examine the significance of the differences detected. A feature indicating inter-individual variation in the body-segment motion for a particular client is referred to as a motion variability, while a feature indicating a difference in the client's motion from a standard or an average value can be called a motion deviation.

There have been a few attempts to quantify motion deviation in some areas. Manal et al.[3] quantified the motion deviation of their clients during gait by using the concept of the z score, and described the algorithmic development of the color-coding method used to make the data presentation easy to understand. Waragai et al.[4] used the z score for the evaluation of brain perfusion SPECT. These examples show that the z score can be used as an index to quantify the motion deviation. Since Ae et al.[1] concluded that motion variability can be used to identify critical points and technical faults, combining the coefficient of variation of the averaged motion pattern as an index of motion variability with the z score of the client's motion as an index of motion deviation allows us to evaluate and diagnose the client's motion in a more detailed manner to determine how serious the deviation is or whether the deviation in the client's motion from the model is allowable.

The purpose of this paper is to propose a biomechanical method to quantify motion deviation in the evaluation of sports techniques, using the example of a basketball set shot in which the motion deviation from a standard motion was quantified by the z score. The concept of a weighted z score is introduced for the determination of the importance of the motion deviation.

2. METHODS

2.1 Subjects and the motion used as a sample

The motion used as a sample was a basketball set shot that was performed by twenty-six female players (height, 1.68 ± 0.07m; body weight, 59.2 ± 5.3kg) from the varsity basketball club at the University of Tsukuba. The subjects were divided into two groups, based on a coach's evaluation. Twelve players were referred to as an excellent group and other fourteen players were as an ordinary group. Before data collection, the subjects were given an explanation of the experiment and the purpose of the study, and written informed consent was obtained from those subjects who agreed to participate in the experiment.

The distance between the shoot line and the basket backboard was 4.6m, and the height of the hoop was 3.05m from the floor. The distance and height of the hoop were decided according to the official rules of basketball. The subjects were asked to shoot a ball into the hoop in a manner as close as possible to that used in a real game situation. We used the set-shot motion in which shots were successfully completed as the sample motion. There were two types of set shot motion used by the subjects, one a single-handed type in which the players released the ball with a single hand, and the other a double-handed type in which the ball was released from both hands.

2.2 Data collection and processing

In this study, we collected the kinematic data of the set shot from twenty-six subjects in two sessions. In the first session, the subjects were six players of the single-handed type and eight players of the double-handed type. We adopted two successful set shots for detailed analysis from each players, i.e. twelve trials for the single-handed type and sixteen trials for the double-handed one in total. In the second session, the subjects were ten single-handed type players and two double-handed ones. We adopted three successful set shots from each players, i.e. thirty for the single-handed type and six trials for the double. Therefore, the total number of trials used for the detailed analysis was forty-two for the single-handed type and twenty-two for the double-handed type.

The positions of forty-nine reflective markers on the surface of the subject's body and four markers on the surface of the basketball were captured to calculate three-dimensional coordinate data for the endpoints of the body segments, using a VICON 612 system (Oxford Metrics Co.) with nine cameras operating at 120Hz.

Twenty-five segment endpoints were calculated from the captured data. The coordinate data were smoothed with a Butterworth low-pass digital filter with optimal cut-off frequencies, determined by the residual error method proposed by Wells and Winter[5], ranging from 5 to 15Hz. Fifteen segment angles, including the elbow and knee joint angles, were calculated in this study.

The set-shot motion was divided into (1) the instant that the right greater trochanter began to descend, (2) the instant that the right knee was maximally flexed, and (3) the moment of ball release. The motion phase between (1) and (2) was referred to as the downward phase, and the phase between (2) and (3) as the upward phase. The three-dimensional coordinate data were normalized by the motion-phase time and the subject's height, and the angles of the segments and joints were normalized by the motion-phase time.

We provided two standard motions for the basketball set shot using the method of Ae et al.[1] The motions were a single-handed shot motion based on forty-two trials, and a double-handed shot motion based on twenty-two trials.

2.3 Calculation of motion variability

The coefficient of variance (henceforth, *CV*) of the segment and joint angles was calculated as an index of the motion variability in the set-shot motion. With the segment and joint angles changing with time and crossing the zero reference, the *CV* acutely jumped up and down due to division by zero or a very small mean value. This is because of the violation of the statistical principle that the *CV* should not be applied to variables involving a negative value. To solve this problem, Ae et al.[1] introduced the concept of a modified *CV* (henceforth, *mCV*) in which the standard deviation is divided by the sum of the mean and range of a variable. We calculated the *mCV* of the segment and joint angles using the following equation (1):

$$mCV_i = \frac{SD_i}{\bar{x}_i + (180 - \bar{x}Min)} \times 100 \quad (1)$$

where SD_i is the standard deviation of the segment or joint-angle data, $\bar{x}_i$ is the mean, and $\bar{x}Min$ is the minimum value of the mean $\bar{x}_i$ over the whole phase.

Average *mCV*s during the downward and upward phases were calculated using the following equation (2).

$$\overline{mCV} = \frac{\frac{1}{n}\sum_{i=1}^{n} SD_i}{\frac{1}{n}\sum_{i=1}^{n}(\bar{x}_i + (180 - \bar{x}Min))} \times 100 \quad (2)$$

2.4 Calculation of motion deviation

The z score was calculated as an index of motion deviation using the following equation (3):

$$d_i = \frac{x_i - \bar{x}_i}{SD_i} \quad (3)$$

where d_i is the z score, x_i is the subject's data at time i, and $\bar{x}_i$ and SD_i represent the mean and standard deviation at time i.

Positive and negative average deviations were calculated using equations (4) and (5):

$$\bar{d}_{pos} = \frac{1}{n}\sum_{i=1}^{n} d^{+} \quad (4)$$

$$\bar{d}_{neg} = \frac{1}{n}\sum_{i=1}^{n} d^{-} \quad (5)$$

where d^{+} is the positive value of the z score and d^{-} is the negative value of the z score.

3. RESULTS AND DISCUSSION

3.1 Standard motions and *mCV*

The success rate of the set shot for the excellent group was 81.7 ± 24.0% and that of the ordinary group was 54.5 ± 29.9%. The rate of the excellent group was significantly greater than that of the ordinary group ($p<0.05$). This implies that the coach's evaluation was reasonable and proper in distinguishing the technical difference between the two groups.

Sixteen players released the ball with a single hand, and ten players used a double-handed type of shot. Figure 1 illustrates the standard motions of two types of set shot, i.e. a single-handed type and a double-handed type. Although it would be interesting to discuss which type of set shot is superior, what differences are identified between the two types, and so on, these questions are beyond the scope of this paper, whose purpose is to propose a method for quantifying motion deviation in the biomechanical evaluation of sports techniques. Therefore, we confine the results and discussion presented in this paper to those of the single-handed type of set shot because the single-handed set shot is more frequently in recent games, and is considered to be easier in analyzing because of focusing on the right hand.

Figure 2 depicts the average *mCV* of the segment and joint angles for a single-handed shot during the downward and upward phases. Although the average *mCV* of the left hand was larger than that of the right hand in both phases, the motion of the left hand was

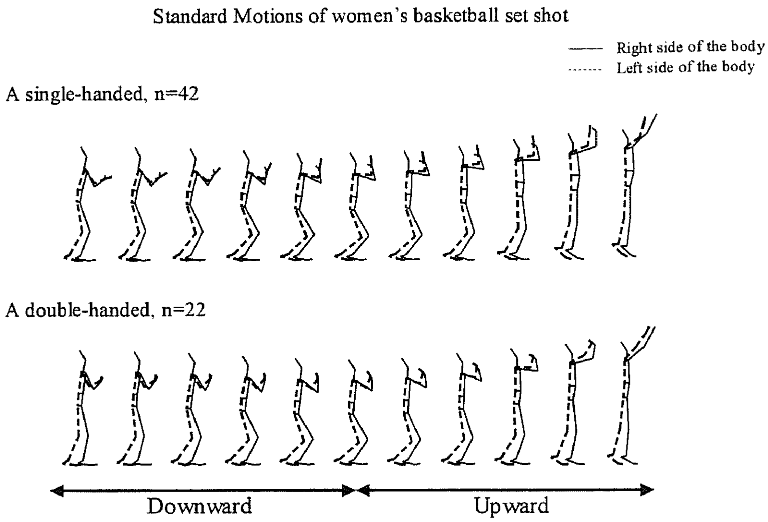

Fig. 1. Standard motions of single-handed and double-handed basketball set shots.

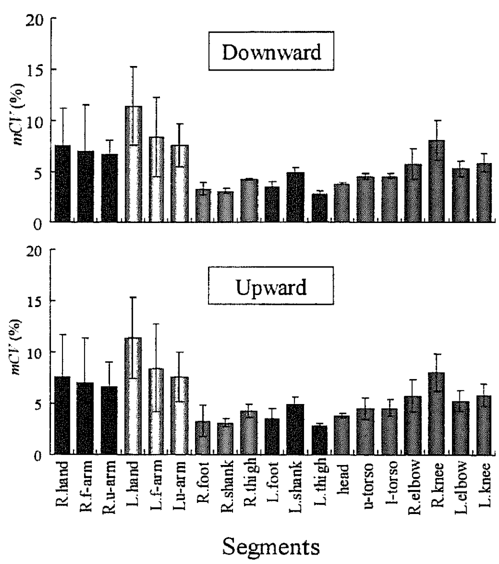

Fig. 2. Average coefficients of the variation in segment and joint angles for a single-handed shot. The large mean *CV* means that the motion variability of the segment was large during the phase.

not critical to the single-handed set shot because the dominant hand of the players was the right hand. The *mCVs* for the right arm and knee were larger than those of the leg segments, head, and torso. This result suggests that players of this skill level move their legs and trunk in a similar manner, but that there might be some differences in the right-arm motion, which was closely related to the success of the shot.

3.2 Evaluation of players' techniques using the z score and *mCV*

Figure 3 presents stick pictures of two players randomly chosen from the excellent and ordinary groups. Although excellent player A's motion seems to be similar to the standard motion seen in Fig. 1, ordinary player B's trunk leaned further backward during the upward phase than in the standard motion. Since basketball coaching theory[2] says that the trunk should be slightly forward or vertical during a set shot, the motion of ordinary player B may be evaluated as a not-so-good technique.

Next, we discuss how the z score and *mCV* are utilized for the technical evaluation. Figure 4 illustrates changes in the average right upper-arm

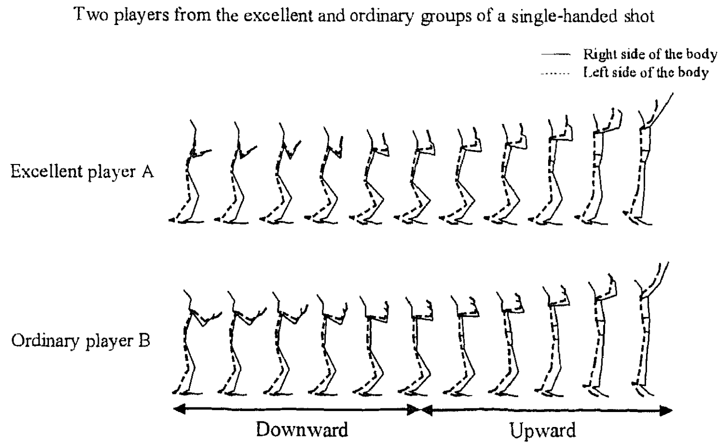

Fig. 3. Stick pictures of two players performing a single-handed shot.

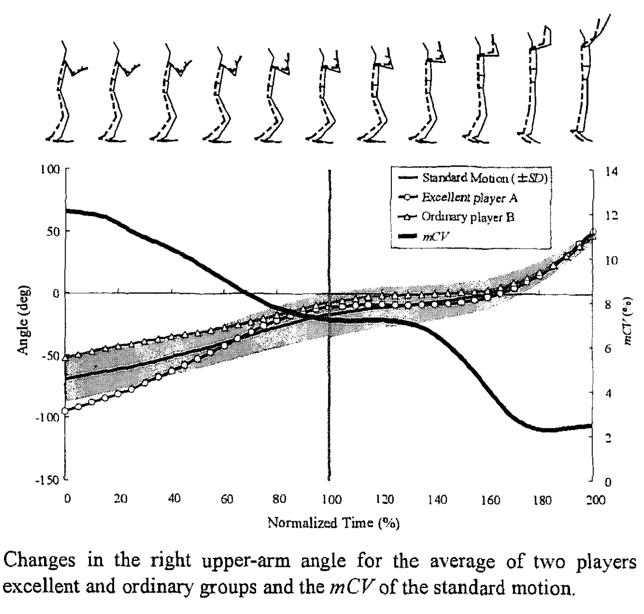

Fig. 4. Changes in the right upper-arm angle for the average of two players from the excellent and ordinary groups and the *mCV* of the standard motion.

angle for two players from the excellent and ordinary groups and the *mCV* of the standard motion. The shaded area indicates a range of one standard deviation. Figure 5 shows changes in the z score of the right upper-arm angle for the two players. The upper-arm angle of ordinary player B positively deviated from the average in the downward phase and most of the upward phase. This indicates that the right upper arm of player B continued moving to a higher position than that of the standard motion. On the other hand, the upper-arm angle of excellent player A negatively deviated in the downward phase and the z score in the upward phase was smaller than that of player B, although it increased before the release. This indicates that player A moved her upper arm to a lower position during the first half of the downward phase, but raised it in a pattern similar to that of the standard motion, quickly lifting it to the higher position before the release.

Figure 6 presents the average z scores for the

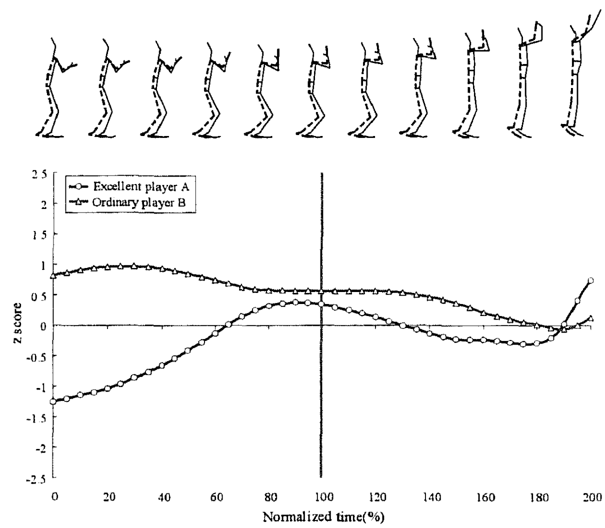

Fig. 5. Changes in the z score of the right upper-arm angle for the two players performing a single-handed shot.

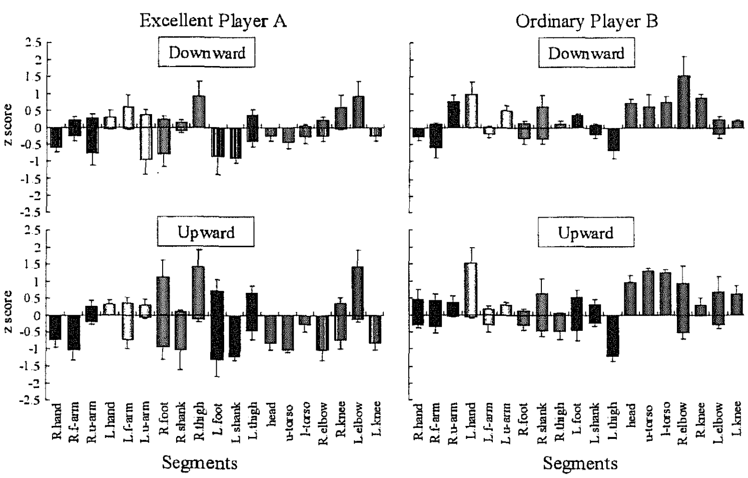

Fig. 6. Average z scores of segment and joint angles for two players performing a single-handed shot. The positive z score indicates that the extension of the segment was larger than the standard motion and the negative one means that the segment was more flexed than the standard motion.

segment and joint angles of players A and B during the downward and upward phases. We referred a larger or smaller z score than 1.0 as a large or small z score in Figure 6. Although the average z scores of excellent player A tended to be small in the downward phase, the z scores of the legs and elbows were large in the upward phase. These results indicate that the motion of the legs for player A deviated further from the standard motion in the upward phase. The average z scores of the upper-torso and right upper-arm and right-elbow angles for ordinary player B were large in the downward phase, and in the upward phase of the score for the upper-torso and left-hand angles of ordinary player B was also large. These results indicate that the motion of the upper body of the player B deviated further from the standard motion during both phases, corresponding to the observations in Figs. 3 to 5.

3.3 Identification of correction points using the weighted z score

There are various combinations of the z score and *mCV*. The technical evaluation based on the relationship between the z score and *mCV* can be summarized as seen in Fig. 7. Case (1), in which both the z score and *mCV* are large, indicates that there may be large individual differences and/or critical technical points if there is a significant relationship with performance. Case (2), in which the z score is large but the *mCV* is small, indicates there may be technical points to be corrected. Case (3), in which the z score is small and the *mCV* is large, indicates no remarkable fault unless the variable in question is significantly related to performance, since the subject's motion is similar to the standard motion. Case (4), in which both the z score and the *mCV* are small, indicates that the subject's motion corresponds well to the standard motion and that there is no remarkable fault. This discussion leads to the idea that the z score, i.e. the motion deviation, should be interpreted in combination with the motion variability for the evaluation of sports techniques and the identification of correction points. Therefore, the weighted z score was introduced on the hypothesis that motion with small *mCV* indicates less allowable individual difference in the motion and is important because most of the subjects performed a similar motion to perform the motion task. We calculated the weighted z score to identify correction points in the techniques using equation (6).

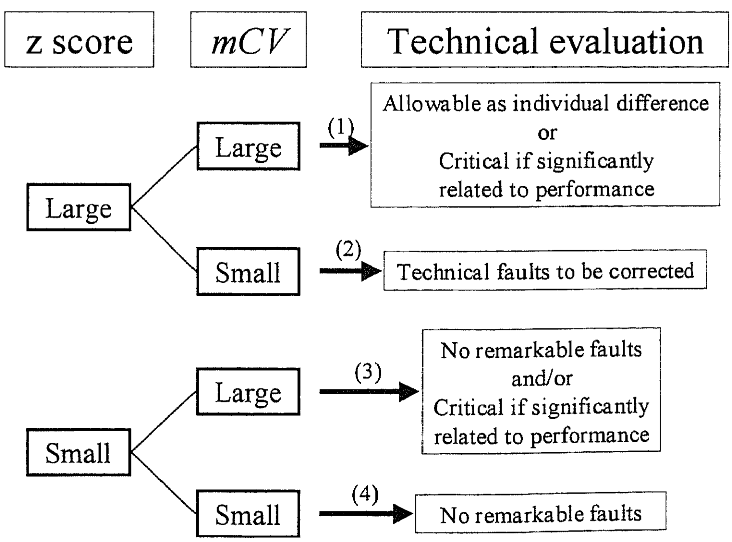

Fig. 7. A chart for the evaluation of sports technique using the z score and *mCV*.

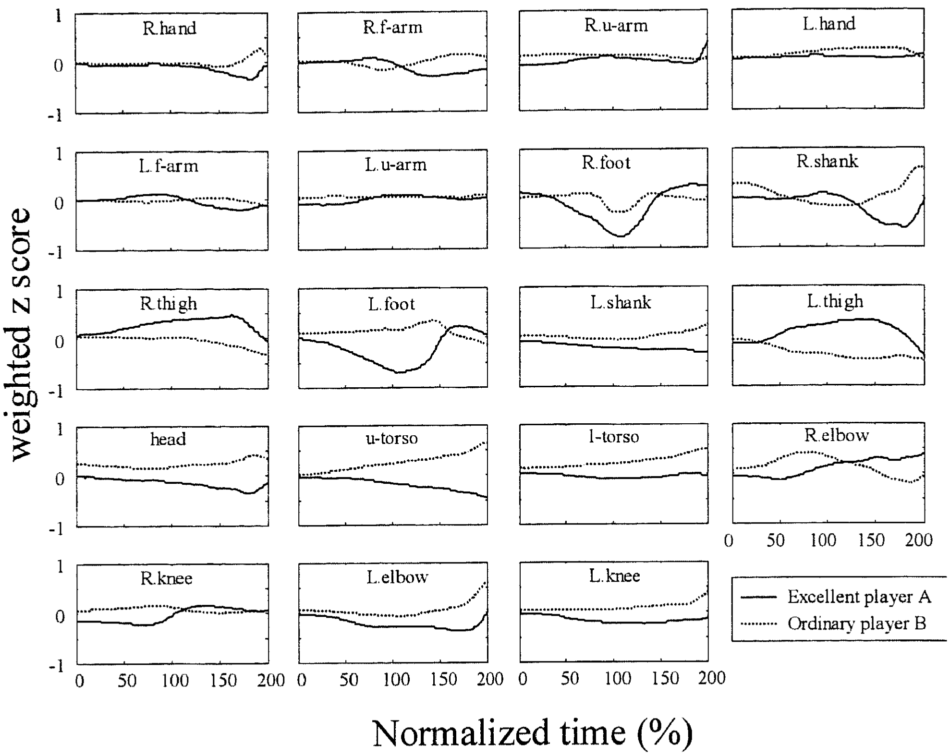

Fig. 8. Changes in the weighted z scores of segment and joint angles for two players performing a single-handed shot. The period of the large weighted z score implies that there may be some technical faults to be corrected in that period. In this example, the positive weighted z score indicates that the extension was larger than the mean.

$$wd_i = d_i \times \frac{1}{mCV_i} \tag{6}$$

Here, wd_i is the weighted z score.

Figure 8 presents an example of changes in the weighted z scores of the segment and joint angles for players A and B. Contrary to our expectation, the weighted z scores for the segment and joint angles of player A were larger in the right leg segments, the left foot, and the thigh than those for player B. Player B had a larger weighted z score for the right hand, shank, head, upper and lower torso, right and left elbow, and left knee. These results suggest that even excellent player A had large motion deviation from the standard motion and should correct her leg motion. However, the number of segments with large motion deviation was greater for player B than for player A. It may be worthy of note that the motion deviation of player B was large in the right hand, head, and trunk during the upward phase.

In Fig. 3, we see from the observation of the set-shot motion that player B leaned her trunk backward during the upward phase. The results obtained from an examination of the weighted z score correspond well to the subjective observation. In addition, a large motion deviation was detected in the leg segments of player A and the leg and arm segments of player B. These deviations would not be easy to determine from simply observing the motion even if visual devices such as a video image were used. This indicates that the method proposed in this study can be effective for determining suitable correction points for specific techniques. In this way, technical correction points could be identified using the weighted z score. However, we would require further examination and discussion with the coaches and players in question as to whether the points identified were indeed serious technical faults requiring correction, and if so how that correction should be carried out.

Although we used the z score for various body angles as examples in this paper, the weighted z score can be applied to other biomechanical parameters such as position, velocity, acceleration, and joint torque.

4. CONCLUDING REMARKS

This paper proposed to quantify motion deviation from a standard motion by using the z score and *mCV* as indexes and to demonstrate how to identify technical correction points for the player's motion. The following can be concluded.

* The *mCV* and z score can be used as respective indexes of motion variability and motion deviation.
* The *mCV* can used to detect critical points for sports techniques.
* The z score can be used to quantify deviations of a player from a model technique.
* The weighted z score can be used to identify a client's technical faults and correction points.
* Figure 7 is a chart of effective evaluation methods for sports techniques.

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