A BIOMECHANICAL METHOD FOR THE EVALUATION OF SPORTS TECHNIQUES BY STANDARD MOTION, MOTION VARIABILITY AND MOTION DEVIATION

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ABSTRACT
The essential but most difficult steps in an optimization loop of sports techniques are the evaluation and diagnosis of the techniques of students and/or athletes, and the identification of their technical faults and limiting factors. This process is frequently referred to as technique analysis in sport biomechanics but the concept of technical analysis is less well developed. Teachers and coaches frequently adopt a model technique or a template of model performance approach in which sequential pictures and figures of an outstanding athlete or skilled performer are used as a motion pattern model. This paper proposes a biomechanical method for the evaluation of sports techniques in which an averaged motion pattern of skilled performers is used as a standard motion, and motion variability and motion deviation are employed as indices to identify critical technical points and faults of an athlete.
KEYWORDS: evaluation, sports techniques, standard motion, motion variability, motion deviation

INTRODUCTION

We will first observe the performance and motion of athletes and will then compare their technique and motion with those of superior athletes as a model to improve and optimize those techniques. We will then evaluate and diagnose the athletes' technique and motion and identify technical faults or limiting factors. Finally, we will attempt to teach him or her to modify his or her technique and motion through appropriate technique training. The essential but most difficult process in this optimization loop is evaluation and diagnosis of the motion and identification of technical faults and limiting factors. This process is frequently referred to as technique analysis in sport biomechanics. The methods of technique analysis have been categorized as qualitative, quantitative, and predictive (Lees, 2002). Although integration and cooperative use of these three approaches would be most effective in teaching and coaching sports techniques, they have not yet been fully developed in the literature and research, much less in the field of teaching and coaching.

It is well known in the field of teaching and coaching that the first step to learning and improving sports techniques is to emulate the motion of superior, skilled performers as a template of model performance. Teachers and coaches frequently adopt a model technique or a template of model performance approach in which sequential pictures and figures of an outstanding athlete or skilled performer are used as the motion pattern model. This approach has some limitations; there may be individual differences even in a model technique that can be attributed to the characteristics of the model athlete, and there is no firm, valid base for determining model technique or ideal form. However, we can overcome these limitations if we prepare some appropriate motion pattern models for sports techniques, which is not always an ideal model but an average or standard motion pattern.

This paper proposes a biomechanical method for the evaluation of sports techniques in which an averaged motion pattern of skilled performers is used as a standard motion, and motion variability and motion deviation are employed as indices to identify critical technical points and faults of an athlete and/or a student.

METHODS

1. Creation of standard motion from motion analysis data

The procedure to create the standard motion is divided into three basic steps, as follows.

Step 1: Collect two- and three-dimensional coordinate data of the body segment endpoints of skilled performers during the performance of sports techniques in experiment situations or official competitions.

Step 2: Normalize coordinate data relative to a reference point, such as the whole body center of gravity or the suprasternale, by anthropometric variables and the time elapsed during each movement phase.

Step 3: Average the normalized coordinate data. The standard motion in this study is the averaged motion pattern of sports techniques.

These steps can be expressed by the following equations.

$$\mathbf{r}_i = \mathbf{R}_i - \mathbf{R}_{rp}$$

$$\mathbf{nr}_i = \frac{\mathbf{r}_i}{H}$$

$$\overline{\mathbf{r}_i} = \frac{\sum_{j=1}^{n} \mathbf{nr}_{i,j}}{n}$$

$$\overline{\mathbf{R}_{rp}} = \frac{\sum_{j=1}^{n} \mathbf{R}_{rp,j}}{n}$$

$$\overline{\mathbf{R}_i} = \overline{\mathbf{r}_i} + \overline{\mathbf{R}_{rp}}$$

where $\mathbf{R}_i$ is the coordinate vector of point *i* normalized to the phase time, *rp* is the reference point, $\mathbf{nr}_i$ is the vector normalized to body height, $\mathbf{r}_i$ is the mean vector, $\mathbf{R}_{rp}$ is the mean vector of the reference point, $\mathbf{R}_i$ is the mean normalized coordinate vector, *H* is the body height, *i* is the point number, *j* is the subject, and *n* is the number of samples.

2. Calculation of motion variability
There are several indicators of motion variability such as coefficient of variation (henceforth, *CV*, Ferrario et al.,1995), mean *CV* of an ensemble average normalized data (Winter, 1984), and transentrophy function (Hatze, 1995). We decided to use the *CV* to express motion variability with a modification to resolve a zero division problem. We modified a *CV* equation to calculate the *CV* of the direction cosines of the body segments to solve this problem; we call it the modified *CV* or mCV.

$$mCV = \frac{SD}{\sum (DC_i + 2)/N} * 100$$

here, *SD* is the standard deviation, DC_i is the direction cosine, *N* is the number of samples, and value 2 is the range of direction cosine, i.e. ±1. It is possible to substitute value 1 for value 2.

3. Calculation of motion deviation
A feature indicating a difference in the client's motion from a standard or an average value or a set value can be called a motion deviation. The z score was calculated as an index of motion deviation using the following equation:

$$d_i = \frac{x_i - \overline{x_i}}{SD_i}$$

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

RESULTS AND DISCUSSION
1. A standard motion of the takeoff technique of elite high jumpers
Figure 1 depicts the standard motion of the high jump takeoff that was created from three-dimensional coordinate data for world-class male and female high jumpers. These data were collected at the 3rd World Championships in Athletics (Tokyo, 1991) using a direct linear transformation technique. A few differences can be observed in the takeoff motions between male and female high jumpers. The male jumpers used a typical double-arm swing in the first half of the takeoff phase, while the female jumpers used a semi-double arm swing. The female jumpers swung their free leg with a deeply flexed knee, while the male jumpers swung their free leg in a more extended manner in the first half of the takeoff. A comparison of the standard

motions of the takeoff enabled us to identify some characteristics of elite male and female high jumpers.

2. Motion variability and identifying critical technical points

We recognize that variability exists even in firmly stereotyped motions and that there will be individual differences among skilled performers. Therefore, all the body segment motions that appear in a standard motion are not always complete, firm, and determinate. We examined the standard motions of various sports and some biomechanical variables and found that some body segments and variables exhibited low variability while others varied significantly. Figure 2 depicts the changes in the *CV* of the joint angles during a high jump takeoff. The *CV* of the shoulder joint angle on the side of the free leg was greater than the angles of the legs, and the *CV* of the takeoff leg knee was smaller than those of the free leg. The smaller *CV*s of the takeoff and trunk than those of the arms and free leg imply that the motions of the takeoff leg and trunk tended to be similar among elite male high jumpers. Thus, the *CV*s of the distal segments tended to be greater than those of the proximal segments. This may be interpreted to indicate that the proximal segments are more important and critical than the distal segments. It also suggests that coaches and athletes in technique training should pay more attention to the motions of the proximal segments, although they are not easily observed by the naked eye.

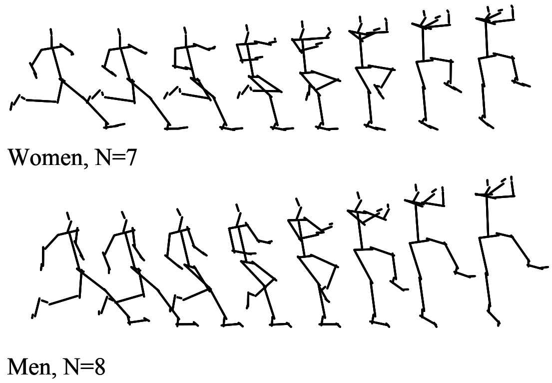

Figure 1 Standard motion of the takeoff technique of elite high jumpers

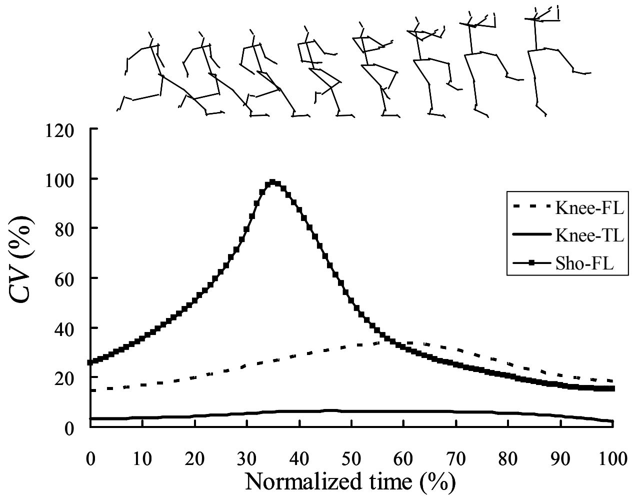

Figure 2 Changes in CV for the joint angles during the takeoff phase of the high jump (FL,Free leg; TL, Takeoff leg)

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

Figure 3 presents stick pictures of two female players from the varsity basketball club of The University of Tsukuba. Although the excellent player A's motion seemed to be similar to the standard motion, the ordinary player B's trunk leaned further backward during the upward phase than the standard motion. Since some basketball coaching manuals say that the trunk should be slightly forward or vertical during a set shot, the motion of the ordinary player B may be evaluated as a not-so-good technique.

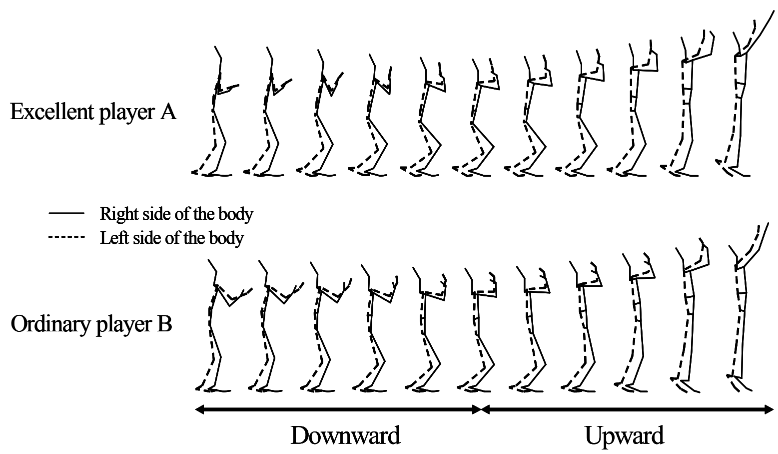

Figure 3 Two players from the excellent and ordinary groups of a single-handed shot

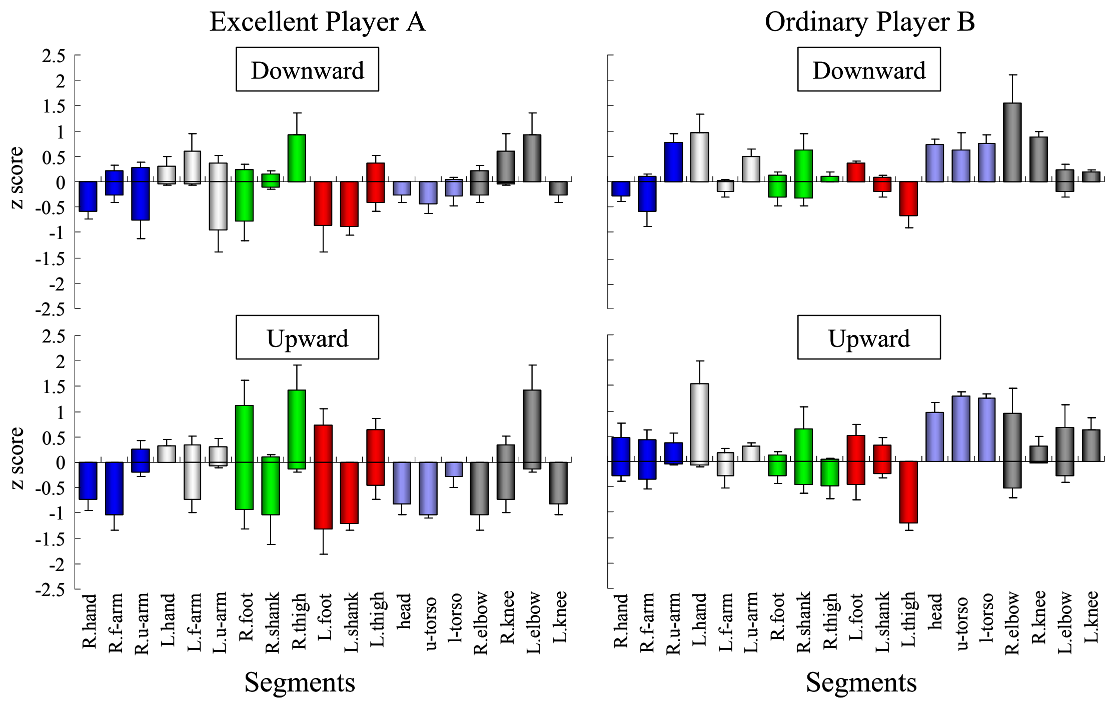

Figure 4 Average z scores of the segment and joint angle for two players performing a single-handed set shot

Next, we discuss how the z score and *mCV* are utilized for the technical evaluation.
Figure 4 presents the average z scores for the segment and joint angles of players A and B during the downward and upward phases of the set shot. We referred a larger or smaller z score than 1.0 as a large or small z score in Figure 4. 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. The average z score of the upper-torso for the ordinary player B was large in the downward and upward phases. 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 Figure 3.

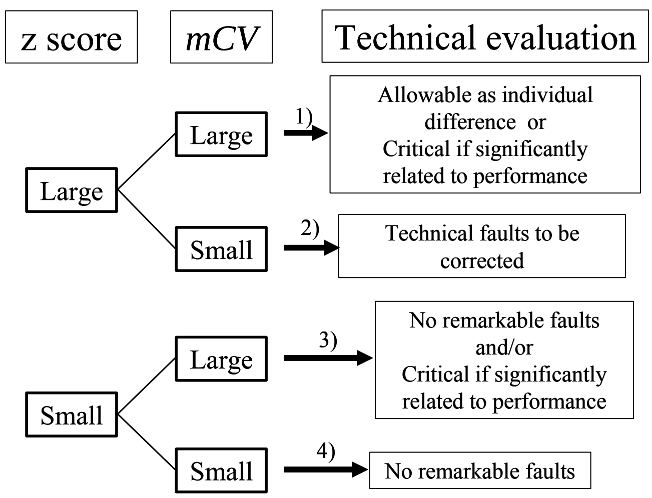

Figure 5 A chart for the evaluation of sports techniques using z score and CV

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 Figure 5. 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.

CONCLUSIONS

The method and concept proposed here can be applied to create a motion pattern template for good sports techniques and a combination of standard motions, motion variability and motion deviation can be used to quantify deviations of a player from a model technique and to identify critical points, limiting factors, and technical faults. There should be several sets of standard motions so that various levels of performers can use them to optimize their sports techniques, depending on their individual skill levels. The standard motion will evolve with an increase in the level of sports techniques of learners and athletes.

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