CLASSIFICATION OF OVERARM THROWING MOTION IN JAPANESE ELEMENTARY SCHOOL GIRLS

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The purpose of this study was to classify the overarm throwing motion of elementary-aged girls. Throwing motion of forty girls from sixth-grade was analyzed three-dimensionally. The z-score of joint angles was calculated as an index of deviation from a standard motion model and used as a variable for cluster analysis. Based on a distance between the clusters, the throwing motions of the sixth-grade girls were classified into three groups. One group had a throwing motion similar to the standard motion model, resulting in significantly longer throwing distances, while the other groups exhibited throwing motions that differed from the standard motion model, e.g., maximum external rotation of shoulder joint was low. These results indicate the potential effectiveness of the standard motion model as a reference in the evaluation of throwing technique.

KEY WORDS: cluster analysis, motion pattern, standard motion model.

INTRODUCTION: Nelson, Thomas, and Nelson (1991) investigated longitudinal changes in children's throwing motion and found that the changes in girls' throwing motions from 5 to 8 years old were much smaller than those of boys. Kobayashi, Ae, Miyazaki, and Fujii (2012) revealed that elementary school girls with short throwing distances exhibited immature throwing motions similar to those of Infant. These results imply that girls typically have more difficulties in improving their throwing motions than boys. Since the mastery of basic movement skills such as throwing can be the foundation for an active lifestyle (Gallahue & Ozmun, 2006), it is important to teach appropriate throwing techniques to girls.

In elementary school physical education classes, teachers typically first observe the performance and motion of children to identify their technical faults. Then, teachers attempt to correct those faults and improve performance through appropriate lessons, practice, and training. The essential but most difficult step in these teaching processes is the evaluation and diagnosis of techniques. One method for evaluating the techniques of children is a comparison of motion patterns of children against established models that describe certain skilled children's motions. Kobayashi, Ae, Miyazaki, and Fujii (2011) established standard motion models of overarm throwing as an average of the motion of skilled elementary-aged girls. Therefore, to enable more effective evaluation of throwing techniques, researchers should describe the motion patterns of overarm throwing for girls. The purpose of this study was to classify the overarm throwing motion of elementary-aged girls and clarify their biomechanical characteristics.

METHODS: Forty girls (age: 12 years; 1.46 ± 0.06 m; 37.5 ± 6.3 kg) from the sixth-grade of two Japanese elementary schools participated in this study. They threw a softball (diameter: 8.5 cm; mass: 141 g) twice at maximum effort in physical education classes, according to the procedures of the Japan Fitness Test regulated by the Japanese Ministry of Education, Culture, Sports, Science and Technology. The regulation specifies the ball size and mass and prescribes that the longer throw of the two trials should be adopted as the best performance. The throwing motion of the participants was videotaped with two high-speed digital cameras (Exilim EX-F1, Casio Co., Tokyo, Japan) operating at 300 Hz. A light-emitting diode synchronizer was used to synchronize the video frames of the movies. The throwing motion with the best performance for each selected girl was analyzed. All selected girls were right-handed throwers.

Twenty-three body landmarks and the center of the thrown softball were manually digitized with a digitizing system (Frame-DIAS II, DKH Co., Ltd., Tokyo, Japan). Three-dimensional coordinate data were reconstructed by the direct linear transformation method and were smoothed with a Butterworth digital filter with cut-off frequencies ranging from 7.5 to 12.5 Hz, decided by the residual method. The throwing motion was divided into striding and throwing phases. The striding phase was defined as the instant of the lowest ball height to the point of stride foot contact, and the throwing phase was defined as the period from stride foot contact to the instant of ball release. Time-series data, including joint angles, were normalized such that each phase represented 100% of the phase time, with 200% of the phase time represented in total.

The height and velocity of the ball at the instant of release and seven kinematic data points (i.e., (1) elbow joint angle of flexion/extension; shoulder joint angles of (2) abduction/adduction, (3) horizontal abduction/adduction, and (4) internal/external rotation; and trunk segment angles of (5) forward/backward lean, (6) lateral lean, and (7) horizontal rotation) were obtained from the three-dimensional coordinate data. The standard motion model established by Kobayashi et al. (2011), which was constructed from the averaged three-dimensional coordinate data from seven skilled girls in sixth grade (age, 12 years; height, 1.45 ± 0.05 m; weight, 35.9 ± 5.9 kg), was used as a reference. The z-score of joint angles was calculated as an index of deviation from the standard motion model using the following equation:

$$d_i = \frac{x_i - M_i}{SD_i}, \quad (1)$$

where d_i is the z-score at time i, x_i is the joint angle, and M_i and SD_i represent the mean and standard deviation, respectively, of the joint angle for the standard motion model.

The z-score at each time was used as a variable for cluster analysis over the time-series data represented by each unit of percent time (seven kinematic data points × 200 percent-time points = 1400 total variables). We used a hierarchical method for cluster classification, square Euclidean distance for the distance between clusters, and Ward's method for merging clusters. Based on the distance between clusters, subjects were classified into groups and averaged motion and z-score were calculated for each group.

The Mann–Whitney U test was used to determine differences in motion deviation between the standard motion model and the motion of each group, and the Kruskal–Wallis test was conducted to test for inter-group differences in throwing distance and ball velocity at release. This was followed by the Mann–Whitney U test with the Holm–Bonferroni correction method to see which pairs of groups were significantly different. The level of significance was set at $p < 0.05$.

RESULTS: Based on the distance between the clusters, the throwing motions of the sixth-grade girls were divided into three groups (Figure 1): Group 1, twelve girls; Group 2, twelve girls; and Group 3, fifteen girls. The throwing distance was 21.8 ± 3.7 m in Group 1, 13.7 ± 2.7 m in Group 2, and 13.4 ± 2.6 m in Group 3. A significant difference in throwing distance was found between Group 1 and Groups 2 and 3 ($p < 0.05$). One girl who stepped forward with the same striding foot as her throwing arm was excluded from the classification of the throwing motion.

Figures 2 and 3 show the averaged motion and z-score of each group relative to the model. For the elbow joint angle (Figure 3a), a significant deviation in flexion was observed in Group 2 between 170% and 190% of normalized time, and in Group 3 between 80% and 170% of normalized time. For the abduction/adduction angle of the shoulder joint (Figure 3b), a significant deviation in abduction occurred in Group 2 from about 140% to 200% of normalized time and in Group 3 from about 190% to 200% of normalized time. Moreover, a significant deviation of adduction occurred in Group 3 from about 60% to 120% of normalized time. For the horizontal abduction/adduction angle of the shoulder joint (Figure 3c), a significant deviation in horizontal adduction was observed in Group 3 from about 50% to 200% of normalized time. For the internal/external rotation angle of the shoulder joint (Figure 3d), deviations in external rotation were observed in Groups 2 and 3 at the middle of the throwing phase and deviations of the internal rotation were observed at around the maximum external rotation in the same groups.

For the forward/backward lean of the trunk (Figure 3e), a significant deviation of backward lean was observed in Group 2 from 140% to 190% of normalized time. For the lateral lean of the trunk (Figure 3f), a significant deviation in leftward lean occurred in Group 2 from 10% to

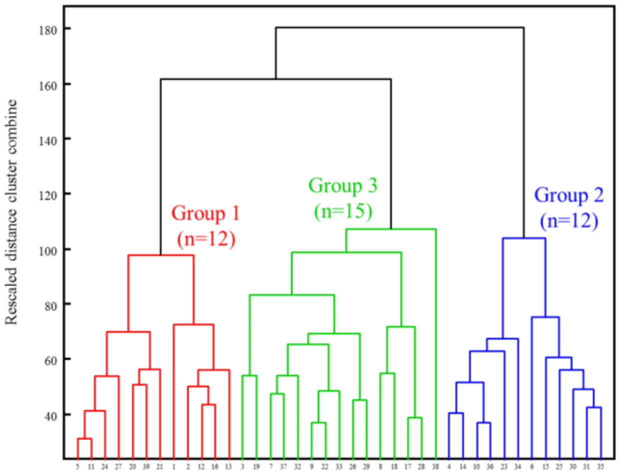

Figure 1. Classification of throwing motions based on deviations from the standard throwing motion model in sixth-grade girls.

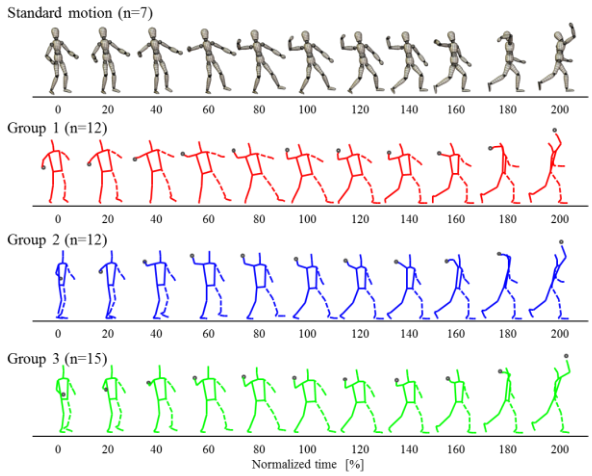

Figure 2. Standard motion models and averaged throwing motions for the three groups of sixth-grade girls.

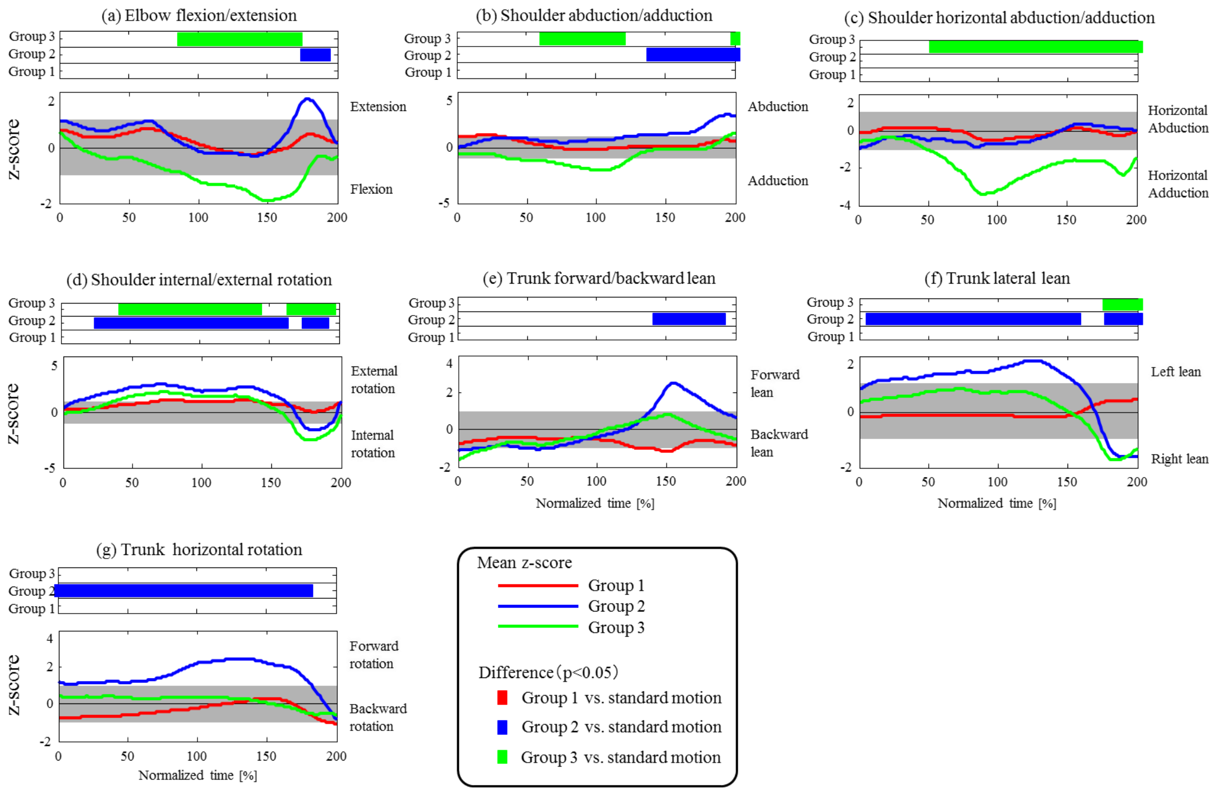

Figure 3. Averaged z-scores for the three groups of sixth grade girls. In each graph, the horizontal axis is the normalized time for the striding and throwing phases, corresponding to 0% to 100% of normalized time and 100% to 200% of normalized time, respectively. A section where a significant difference was observed between each group and the standard motion model is shown in the upper part of the figure. The 100% normalized time point represents the instant the striding foot contacts the ground.

160% of normalized time, and Groups 2 and 3 significantly deviated in rightward lean from about 170% to 200% of normalized time. For the horizontal rotation of the trunk (Figure 3g), a significant deviation in forward rotation was observed in Group 2 from about 0% to 180% of normalized time.

DISCUSSION: Group 1 exhibited the longest throwing distance, and their throwing motion was similar to the standard motion model. In Group 2, backward rotation and rightward lean of the trunk were not observed in the striding phase, the maximum external rotation of the shoulder joint was low, and the shoulder greatly abducted when the ball was released. Although Group 3 shows a lower deviation in trunk motion than Group 2, their throwing arm motion deviated greatly, that is, there was large and horizontal adduction of the shoulder joint and elbow flexion at the time of contact with the ground by the striding foot.

In Groups 2 and 3, since horizontal rotation and lateral flexion of the trunk were less than those of Group 1 and the standard motion model (Kobayashi et al., 2011), it is presumed that the effect of the external rotation of the shoulder by motion-dependent force was small. Therefore, both groups are considered to throw the ball using mainly shoulder abduction before the release, rather than external/internal rotation of the shoulder. This may have resulted in significantly shorter throwing distance than those demonstrated by Group 1 and the standard motion model (21.3 ± 4.1 m). The horizontal adduction of the shoulder before release in Group 3 is considered to be similar to the immature throwing motion identified by Ishida et al. (2006). Accordingly, the throwing motion of Group 3 may be an underdeveloped motion resembling that of other young children.

These results indicate that the throwing distances of sixth-grade girls are longer when their throwing motions are similar to the standard motion model, and their throwing distances are short when their throwing motions deviate greatly from the standard motion model. The use of the standard motion model and classified motion patterns in this study was useful for evaluation and diagnosis in teaching processes and may be effective for the improvement in the throwing techniques and throwing distance of less experienced children. It is necessary to conduct longitudinal studies as follow-up research to investigate how deviations in the throwing motion can be modified through training.

CONCLUSIONS: The throwing motions of the sixth-grade girls were classified into three groups using cluster analysis. One group had a throwing motion similar to the standard motion model, resulting in significantly longer throwing distances, while the other groups exhibited throwing motions that differed from the standard motion model and produced shorter throwing distances. These results indicate the potential effectiveness of the standard motion model as a reference in the evaluation and diagnosis of throwing technique. Accordingly, the results of this study may help in correcting flawed throwing motions and improving throwing performance in elementary school girls.

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