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MECHANICAL ENERGY FLOW IN THE ARM SEGMENTS DURING OVERARM THROWING FOR SKILLED JAPANESE ELEMENTARY SCHOOLBOYS

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The purpose of this study was to investigate the mechanical energy flow in the arm segments during overarm throwing for skilled Japanese elementary schoolboys. The throwing motions of 42 boys from the second, fourth, and sixth grade were videotaped using three high-speed cameras. Seven boys from each grade were selected for 3-D motion analysis, based on their throwing distance. The increases in the mechanical energy of each segment have occurred from proximal to distal segment and the joint force power resulted in greater change in the mechanical energy of the ball and throwing arm segments, regardless of the school grade. The elementary school boys developed the abilities to generate the greater mechanical energy and to flow the generated mechanical energy toward distal segments of the throwing arm by the joint force power.

KEY WORDS: children, motion analysis, throwing development, mechanical power.

INTRODUCTION: In physical education lesson of elementary schools, teachers should prepare appropriate training programs to meet individual students' "readiness". However, they frequently encounter difficulties in determining workouts and practice for children because of a wide range of their developmental and skill levels. In particular, overarm throwing is considered to be one of the most difficult motions to teach, because the throwing arm moves very fast in a three-dimensional space and has a large number of degrees of freedom. The Japanese Ministry of Education, Culture, Sports, Science and Technology (2011) concerns an acute decline in the Japanese children's throwing ability. Therefore, it is important to gain insights into children's throwing motion with regard to age and development in physique for designing appropriate teaching programs.

Many of biomechanical studies on the children's throwing motion have focused on the joint kinematics. In contrast, there are some investigations on the mechanical energy flow in the throwing arm segments of adult's throwers. Jöris, van Muyen, van Ingen Schenau & Kemper (1985) analyzed the overarm throwing of 56 female handball players, and concluded that the consecutive actions of body segments from the larger proximal segments to the relatively smaller distal segments were connected to intrinsic muscle properties and to an energy flow from the proximal to the distal segments. Shimada, Ae, Fujii, Kawamura & Takahashi (2003) analyzed the baseball pitching motion of 22 varsity players, and reported that the great mechanical energy flow into the distal segment due to the joint force power was observed in the throwing arms joints.

Investigation on the mechanical energy flow in children's overarm throwing would enhance understanding of the mechanism of children's throwing motion and provide useful information to design appropriate training programs for the improvement in the throwing performance. Therefore, the purpose of this study was to investigate the mechanical energy flow in the arm segments during overarm throwing for skilled Japanese elementary schoolboys.

METHODS: Forty-two Japanese boys from the second, fourth, and sixth grades of one elementary school participated in this study. They were instructed to throw a softball (8.5 cm in diameter; 141 g in mass) twice with their maximal effort, according to the procedure of the Japan Fitness Test regulated by the Japanese Ministry of Education, Culture, Sports, Science

and Technology, in which the ball size was specified and the longer throw of two trials was adopted as the best performance. The subjects' throwing motion was videotaped using three high-speed digital cameras (Exilim EX-F1, Casio Co., Japan) operating at 300 Hz,
which were synchronized using a light-emitting diode synchronizer.

Based on their throwing distance as determined with a tape measure, seven boys from each grade (second grade, 1.23±0.04 m in height, 24.1±3.1 kg in body mass; fourth grade, 1.36±0.05 m, 33.4±7.3 kg; sixth grade, 1.47±0.05 m, 40.4±6.7 kg) were regarded as good throwers and one throwing motion with the longest throwing distance for each subject was selected for 3-D motion analysis. All selected subjects were right-handed throwers.

Twenty-three body landmarkers defined by Yokoi, Shibukawa & Ae (1986) and the centre of the softball were digitized with a digitizing system (Frame-DIASⅡ, DKH Co., Japan). Three-dimension coordinate data were reconstructed by the DLT method and were smoothed by a Butterworth digital filter with cut-off frequencies ranging from 7.5 to 12.5 Hz, which were decided by the residual method after Winter (2009).

The height, velocity, and angle of the ball at the release were obtained from 3-D data. The location of the centre of mass, mass and the moment of inertia for the subjects' body segments was estimated after the children's body segment parameters of Yokoi et al. (1986). The segments mechanical energy was calculated as the sum of the potential, translational and rotational energy of the segment by using kinematic data. The segments mechanical power was obtained by differentiating the segments mechanical energy by time.

Inverse dynamics with a three-rigid-body model consisting of the upper arm, forearm and hand was used to calculate the joint force and torque at the wrist, elbow, and shoulder of the throwing arm. The joint force power (JFP) was calculated as a dot product of the joint force and the joint velocity, and the power generated by the joint torque (hereafter segment torque power, STP) was calculated as a dot product of the joint torque and the angular velocity of the segment, according to the notation and calculation method of Winter (2009) and Shimada et al. (2004). The joint force power and segment torque power divided by the subject's body mass were normalized by the time of the throwing phase, which was defined from the instant of stride foot contact to the instant of ball release as 100 %.

ANOVA was used to test the effects of school grade on variables, followed by Scheffe's method for a multiple comparison. The level of significance was set at 5 %.

RESULTS: There were significant differences in throwing distance (second graders: 16.30±3.54 m, fourth graders: 25.58±4.50 m, sixth graders: 35.34±4.35 m, $p<0.05$) and ball velocity (second graders: 14.05±1.62 m/s, fourth graders: 17.77±1.92 m/s, sixth graders: 21.76±1.30 m/s, $p<0.05$). No significant differences in release angle and release height ratio relative to body height were found among the three grades.

Figure 1 shows the patterns of the mechanical energy change in throwing arm segments for typical throwers from each grade.

In the sixth grader, the mechanical energy of the upper arm and forearm increased in the middle of the throwing phase, and those of hand and ball sharply increased before the release. Although the magnitude of the mechanical energy of the arm segments was greater in the sixth grader, there was no remarkable difference in the pattern of the change in the mechanical energy among the three grades.

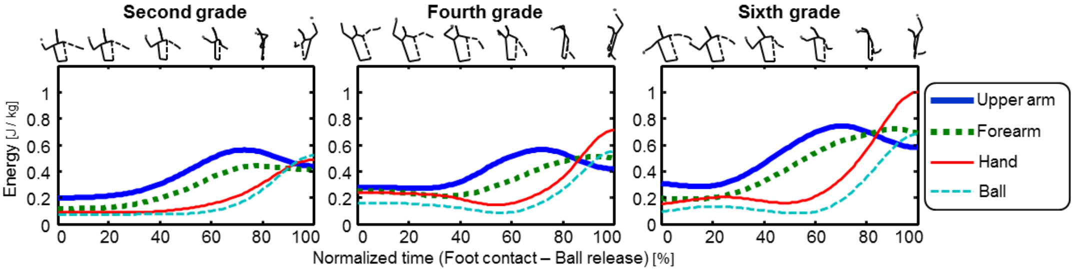

Figure 1: Patterns of mechanical energy of throwing arm segments for the typical throwers.

Figure 2 shows the patterns of mechanical power, joint force power and segment torque power of the upper arm (top), forearm (middle) and hand (bottom) for the throwers from each grade. The mechanical power of the segment is equal to the sum of the joint force powers and the segment torque powers at the proximal and distal ends, which is so-called "mechanical power balance" (Winter, 2009).

upper arm: In these throwers, the joint force power of the shoulder was positive during the throwing phase, while that of the elbow was great in negative power. The positive segment torque power of the shoulder before the release was greater in the sixth grader than those of the second and fourth grader.

forearm: In the sixth grader, after the increase in the positive joint force power of the elbow, a greater negative joint force power of the wrist was exerted before the release. The segment torque power of the elbow was negative in these throwers until 80 % time and changed to the positive just before the release, while the segment torque power of the wrist was close to zero in almost the whole phase.

hand: The mechanical power of the hand of the sixth grader increased toward the release, and its peak was much greater than those of the second and the fourth grader. In these throwers, the positive joint force power of the wrist was exerted before the release, while the segment torque power of the wrist changed slightly from the negative to the positive.

Table 1 indicates the peak joint force power of the shoulder, elbow and wrist for all analyzed throwers.

There were significant differences in the peak joint force powers of all joints between the second graders and the sixth graders ($p<0.05$).

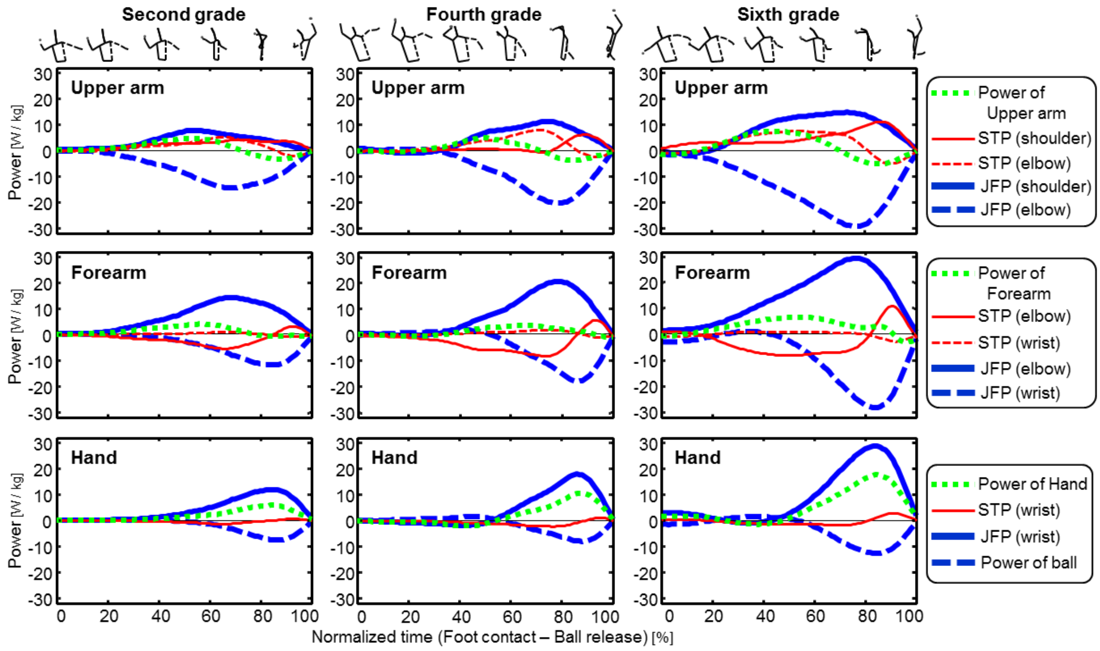

Figure 2: Patterns of mechanical power, joint force power (JFP) and segment torque power (STP) of upper arm (top), forearm (middle) and hand (bottom) for the typical throwers.

Table 1: Peak joint force power of the shoulder, elbow and wrist for all analyzed throwers.

	Second grade (n=7)	Fourth grade (n=7)	Sixth grade (n=7)	Difference (* p<0.05)
Peak joint force power of shoulder [W/kg]	8.49±1.41	11.12±2.51	13.53±2.18	2nd<6th*
Peak joint force power of elbow [W/kg]	18.44±3.41	22.37±6.66	29.28±4.48	2nd<6th*
Peak joint force power of wrist [W/kg]	16.66±3.15	21.90±7.31	26.13±3.71	2nd<6th*

DISCUSSION: The increases in the mechanical energy of each segment have occurred from the proximal to the distal segment in the typical throwers. This pattern of the mechanical energy change indicates that an energy flow between segments took place even in children's overarm throwing via the joint during the throwing phase, as Jöris et al. (1985) pointed out on the female's handball throwing. The energy flow between the throwing arm segments helps to accelerate the ball effectively by the mechanical energy generated by the muscles of the trunk and shoulder which have greater capacity for generating the mechanical energy than the distal ones.
The positive power at the joint of a segment indicates an increase in the mechanical energy of the segment, and the negative power indicates a decrease in the mechanical energy (Winter, 2009). In these throwers, the pattern of change in the mechanical power of the hand was similar to the joint force power of the wrist, and the segment torque power of the hand at the wrist was small in the entire throwing phase. This result indicates that the change in the mechanical energy of the ball is largely influenced by the mechanical energy flow through the joint force power of the wrist which was common in the grades.
The increases in the joint force power of throwing arm joints took place in the similar order as the segments' mechanical energy in the throwers, and the magnitudes of joint force power were greater than those of the segment torque power. These indicate that the change in the mechanical energy of the throwing arm segments depended on the joint force power more than the segment torque power in the overarm throwing, regardless of grade. Furthermore, the peak joint force powers of all joints were significantly greater in the sixth graders than the second graders. Therefore, it is likely that the joint force power of the sixth graders greatly contributed to the large mechanical energy flow from the distal to the proximal segments.
In the sixth grader, there were greater positive joint force power of the shoulder during the whole throwing phase, and the positive segment torque power of the upper arm at the shoulder increased before the release. It is considered that these positive powers at the proximal end of the upper arm of the sixth grader result in the greater joint force power of the elbow more than the second and fourth graders. Kobayashi, Ae, Miyazaki & Fujii (2012a, 2012b) reported that the range of motion of the trunk and the positive joint torque power of the shoulder internal-external rotation increased with the increase in the school grade. It is inferred that the elementary schoolboys generated the mechanical energy by using larger proximal segments with the increase in the school grade and flowed the mechanical energy to the distal segments of the throwing arm by the joint force power. This is one of the developments in boys' throwing motion from a viewpoint of the mechanical energy flow and may be one of reasons of the significant difference in the ball velocity among the three grades.

CONCLUSIONS: The throwing distance and ball velocity significantly increased with increase in the school grade. The increases in the mechanical energy in arm segments occurred from the proximal to the distal segment in the present throwers. The joint force power resulted in the greater change in the mechanical energy of the ball and throwing arm segments than the segment torque power, regardless of the school grade. The peak joint force powers of the arm joints were significantly greater in the sixth graders than the second graders. Thus, the elementary school boys developed the abilities to generate the greater mechanical energy and to flow the generated mechanical energy toward the distal segments of the throwing arm by the joint force power.

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