KINETICS OF OVERARM THROWING MOTION FOR SKILLED JAPANESE ELEMENTARY SCHOOL BOYS

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The purpose of this study was to investigate the kinetics of overarm throwing for skilled Japanese elementary school boys, in order to gain insight into children's throwing motion. The throwing motions of 42 boys from the second, fourth, and sixth grade were videotaped using three high-speed cameras; and seven boys from each grade were selected for 3D motion analysis, based on their throwing distance. Although no difference in the elbow extension torque before the release was observed, the angular velocity and the joint torque of the shoulder external/internal rotation tended to be greater for students of higher grades. Thus, the sixth graders tended to depend more on shoulder external/internal rotation with the effective use of a stretch-shortening cycle of the shoulder muscles, while the second graders seemed to depend more on elbow extension.

KEY WORDS: physical education, basic movements, children, joint torque.

INTRODUCTION: In physical education class in elementary schools, teachers first observe children's performance and motion to identify their technical faults, and then attempt to correct their faults and improve their performance. However, when teachers have to manage training programs appropriately to meet individual students' "readiness" in physical education, they frequently encounter difficulty in determining lessons and practice methods because of the wide range of developmental levels of elementary school children. In particular, overarm throwing is considered to be one of the most difficult motions in the basic movements to teach, since the throwing arm has a 3D nature and a large number of degrees of freedom, and moves very quickly. The Japanese Ministry of Education, Culture, Sports, Science and Technology regards the decline in Japanese children's throwing ability as a serious problem. Therefore, it is important to gain more insight into children's throwing motion, which differs from that of adults.

In recent years, some studies on the throwing motion of children (Ishida, Murata, & Hirano, 2006; Stodden, Langendorfer, Gleisig, & Andrews, 2006) have been conducted, and research findings have accumulated. Kinetics studies on the throwing arm joints can provide useful information to design appropriate training programs in order to improve the throwing performance of children. Fleisig et al. (2006) addressed the kinetics of the throwing arm in the throwing motion of young baseball players, and discussed the risk of injuries with standard and lightweight balls. However, little kinetic information on children's overarm throwing motion exists, and the kinetics of the overarm throwing motion for ordinary elementary school children and their development status have not been clarified. Therefore, the purpose of this study was to investigate the kinetics of overarm throwing for skilled Japanese elementary school boys, in order to gain insight into children's throwing motion.

METHODS: Forty-two Japanese boys of one elementary school (second, fourth, and sixth grades) participated in this study. They were instructed to throw a softball twice (8.5cm diameter; 141g mass) 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 is specified and the longer throw of two trials is adopted as best performance. The subjects' throwing motion was videotaped using three digital movie cameras (Exilim EX-F1, Casio Co., Japan) operating at 300Hz. All cameras data were synchronized using a light-emitting diode synchronizer and were downsampled to 150Hz to shorten time-consuming digitizing. The sampling rate of 150Hz is likely to be acceptable for analysis of nonathlete children's throwing motion because children's release velocity was nearly half that of good adult throwers.

Based on their throwing distance as determined with a tape measure, seven boys for each grade (second grade, 1.23 ±0.04 m, 24.1 ±3.1 kg; 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 selected as good throwers for 3D motion analysis; and one throwing motion with the best performance for each selected subject was analyzed. All selected subjects were right-handed throwers.

Twenty-three body landmarks and the center of the softball were digitized. 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. The velocity, height, and release angle of the ball at the release were computed. Motion analysis software (MAP system) developed and written on the MATLAB base in the Laboratory for Sport Biomechanics, University of Tsukuba, was used to reconstruct the coordinate data and to calculate biomechanical variables.

Inverse dynamics with a three-rigid-body model consisting of the hand, forearm, and upper arm segments was used to calculate the joint torques at the wrist, elbow, and shoulder of the throwing arm. Joint torque power was calculated as a dot product of joint torque and joint angular velocity. Time series data were normalized by the time of the throwing phase, which was defined from the instant of the stride foot contact to the instant of the ball release as 100%, and then averaged every 1% time.

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

RESULTS: Table 1 lists the throwing distance, ball velocity, release angle and height for good throwers from each grade. Throwing distance and ball velocity significantly increased with an increase in school grade ($p<0.05$). No significant difference in release angle was found between grades. Release height of the second graders was significantly lower than that of the sixth graders ($p<0.05$), although the release height ratio relative to body height was the same among the three grades (not shown in Table 1).

Table 1
Throwing distance, ball velocity, release angle, and height for good throwers from each grade.

	Throwing distance [m]	Ball velocity [m/s]	Release angle [deg]	Release height [m]
Grade 2 (n=7)	16.30±3.54	14.05±1.62	31.9±11.7	1.38±0.05
Grade 4 (n=7)	25.58±4.50	17.77±1.92	30.4±6.9	1.52±0.09
Grade 6 (n=7)	35.34±4.35	21.76±1.30	28.9±4.5	1.58±0.12
	*	*	n.s.	*

*p<0.05

Figure 1 plots averaged patterns of joint angular velocity (top), joint torque (middle), and joint torque power (bottom) of elbow flexion/extension (left), shoulder internal/external rotation (center), and shoulder abduction/adduction (right).

The elbow joint quickly extended before the release (100% time), and the peak extension angular velocity increased with increasing school grade (2=4<6, $p<0.05$). The flexion torque was exerted before the extension torque was exerted in the last part of the throwing phase, but the magnitude of the peak extension torque did not differ, regardless of grade. Elbow joint torque power was close to zero in the first half of the throwing phase, became negative at 80% time, and then changed to positive before the release. The peak positive power of the sixth graders was greater than that of the other two grades (2<6, $p<0.05$).

The shoulder joint rotated externally after the foot contact and internally just before the release, and the internal rotation of the sixth graders at the instant of the release was faster than that of the other two grades (n.s.). The internal rotation torque was exerted throughout the throwing phase and peaked at 80% time in all grades. The peak internal rotation torque of the sixth graders was greater than that of the second graders and the fourth graders (2<6, $p<0.05$). The shoulder internal/external torque power was negative until 80% time and positive before the release, and the negative (2<6, $p<0.05$) and positive (n.s.) peak torque power were greater in the sixth graders than in the second and fourth graders.

Different abduction-adduction patterns were observed between the second grade and the other two grades. The fourth and sixth graders abducted the shoulder joint after the foot contact and adducted before the release; in contrast, the second graders abducted in the second half of the throwing phase. The abduction torque was constantly exerted in all participants, and the peak abduction torque increased with increasing school grade (2<6, $p<0.05$). Shoulder abduction/adduction torque power was negative before the release, although no great torque power was generated.

Figure 2 plots averaged patterns of joint force acting on the distal endpoint of the upper arm. Since the joint force vector is projected onto the local coordinate system of the shoulder joint, positive joint force is upward and negative joint forces is downward (Y_{sh} in Figure 2). The joint force was negative in the second half of the throwing phase, and the peak negative value at 80% time was greater in the sixth graders than in the second graders and the fourth graders (2<6, $p<0.05$).

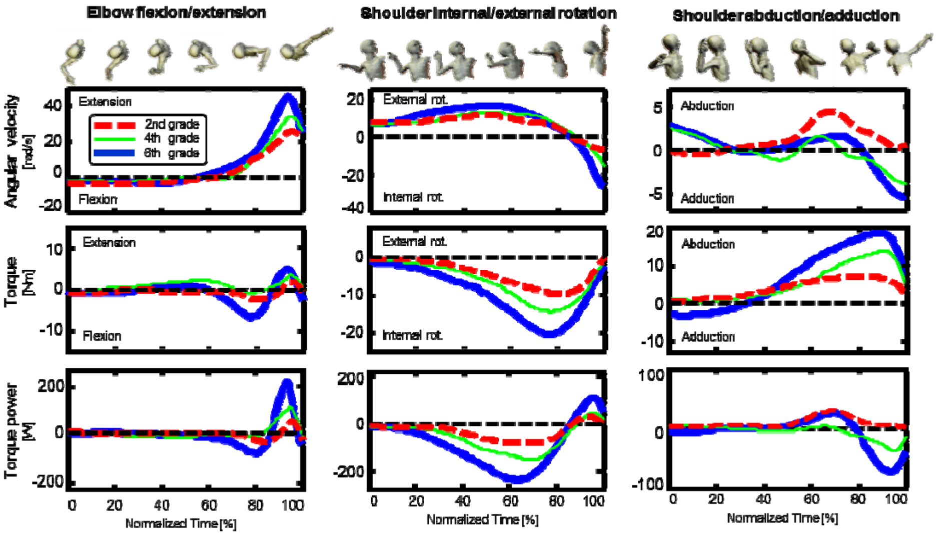

Figure 1: Averaged patterns of joint angular velocities (top), joint torques (middle), and joint torque powers (bottom) of the elbow flexion/extension (left), the shoulder internal/external rotation (center), and the shoulder abduction/adduction (right) of the throwing arm of skilled boys.

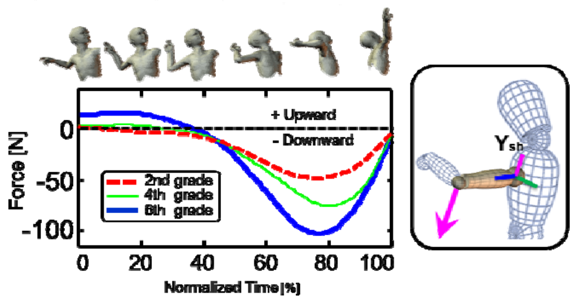

Figure 2: Averaged patterns of the joint force acting on the distal endpoint of the upper arm. The value indicates the magnitude of Y_{sh} component of the joint force projected onto the local coordinate system of the shoulder joint.

DISCUSSION: Although the extension angular velocity of the elbow joint increased with school grade, no remarkable difference in elbow extension torque was observed in the final part of the throwing phase. These results imply that there may be different ways to extend the elbow joint for accelerating the ball from the elbow extension torque. Considering the kinetics of the elbow joint, one possibility is derived from Feltner and Dapena's (1986) statement that the extension of the elbow joint is not due primarily to the action of the triceps but to the resultant joint force exerted by the upper arm on the forearm at the elbow. It is inferred from the small magnitude of the elbow extension torque and this remark of previous researchers that the ball's acceleration may result from the motion-dependent force at the elbow joint rather than the elbow extensors, regardless of grade. The kinematics of the trunk was not presented in the figure due to the limitation of space. However, as inferred from the series of figures in the upper-left portion of Figure 1, since the trunk quickly rotated counterclockwise about its longitudinal axis in the middle part of the throwing phase, the joint force at the elbow associated with centripetal acceleration could induce the elbow extension. In contrast, the elbow flexion torque exerted in the latter part (60 to 80% time) can be interpreted as inhibiting too early an elbow extension, which would have been induced by the effect of the motion-dependent force, as mentioned above.

The shoulder joint of the second graders consistently abducted, whereas that of the fourth and sixth graders adducted before the release. It is noteworthy that the shoulder abduction torque of the fourth and sixth graders was much greater than that of the second graders. The magnitude of the downward joint force of the fourth and sixth graders reached its maximum when the shoulder began to adduct, and was similar to the changes in the shoulder internal/external rotation torque (Figure 2). This joint force could be explained by the angular acceleration of the forearm due to the shoulder internal torque. This downward force produced the adduction moment about the shoulder joint, which would partially explain why the fourth and sixth graders adducted the shoulder before the release, although they exerted large abduction torque in the corresponding period. This implies that the sixth graders intended to raise their upper arm by exerting the abduction torque at the shoulder joint.

As the grade increased, continuous internal rotation torque generated great negative power in the middle of the throwing phase. This negative power could be exerted by the eccentric muscles of the shoulder external rotation, which might enhance greater positive torque power before the release. Moreover, the mechanical energy generated by the positive joint torque power in the sixth graders increased the mechanical energy of the upper limb and accelerated the ball. Thus, the sixth graders tended to depend more on shoulder external/internal rotation with the effective use of a stretch-shortening cycle of the shoulder muscles, while the second graders seemed to be more dependent on elbow extension. This is one of the characteristics of the development of boys' throwing motion, and explains the significant difference in ball velocity among the three grades.

CONCLUSIONS: Throwing distance and ball velocity significantly increased with increasing school grade. The elbow extension before the release became faster, although the magnitude of the peak extension torque at the elbow joint was almost the same, regardless of grade. Angular velocity and joint torque of the shoulder internal/external rotation tended to increase as the grade increased. Although the abduction torque was continuously exerted in all grades, the second graders consistently abducted the shoulder, whereas the fourth and sixth graders adducted the shoulder before the release. However, the sixth graders tended to depend more on the shoulder external/internal rotation with the effective use of a stretch-shortening cycle of the shoulder muscles, while the second graders seemed to be more dependent on elbow extension.

REFERENCES:

Feltner, M. & Dapena, J. (1986). Dynamics of the shoulder and elbow joints of the throwing arm during a baseball pitch. *International Journal of Sport Biomechanics*, 2, 235-259.

Fleisig, G.S., Phillips, R., Shatley, A., Loftice, J., Dun, S., Drake, S., Farris, J.W. & Andrews, J.R. (2006). Kinematics and kinetics of youth baseball pitching with standard and lightweight balls. *Sports Engineering*, 9, 155-163.

Ishida, K., Murata, M. & Hirano, Y. (2006). Shoulder and elbow kinematics in throwing of young baseball players. *Sport Biomechanics*, 5, 183-196.

Stodden, D.F., Langendorfer, S.J., Gleisig, G.S. & Andrews, J.R. (2006). Kinematic constraints associated with the acquisition of overarm throwing part II:Upper extremity actions. *Research Quarterly for Exercise and Sport*, 77, 428-436.