MOTION ANALYSIS OF OVERHAND THROWING: PAST, PRESENT, AND FUTURE

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Overhand throwing motion is often regarded as one of the basic motions along with walking, running, and jumping. Three-dimensional (3-D) image analysis of the kinematics and kinetics using of rigid body segment model of overhand throwing motion has been studied widely in recent years. In this paper biomechanical research on throwing is reviewed with a special focus of studies from Japan. Considering throwing is not an ontogenic but rather a phylogenic motion, more thorough and longitudinal studies on various aspects of skill development and training would be expected. The fact that the trunk, shoulder, and hand are difficult to model as a single rigid body has limited research depth. Studies linking advanced 3-D motion analysis and musculo-skeletal modeling are required if a better understanding of the biomechanics of overhand throwing motion are to result.

KEY WORDS: biomechanics, 3-D analysis, kinematics, kinetics, link segment model

INTRODUCTION: Overhand throwing has been extensively studied in Japan and the USA, with many research papers published on baseball pitching. A number of reviews summarizing these studies have been published (Atwater, 1979; Fleisig et al. 1996).
In this paper, the characteristics of the overhand throwing motion will be discussed, followed by brief review of studies published by Japanese researchers. Future research direction in this area will also be discussed.

WHAT IS "OVERHAND THROWING"?
"Overhand" does not necessarily mean the position of the throwing arm. In cricket bowling, the arm is swung through an overhead position (Figure 1). But this motion is not called overhand throwing. In baseball, there are pitchers with "overhand", "three-quarter", "sidehand", and "underhand" styles. They look initially different to each other. But if close attention is paid to the angles of upper limb joints, all are similar, with differences highlighted in trunk angle (Figure 2).

There are several types of throwing motion, such as bilateral or unilateral, and overhand, sidehand, or underhand. Among these unilateral overhand throwing is a motion which is acquired last from the developmental view-point (Wickstrom, 1975). In softball and cricket,

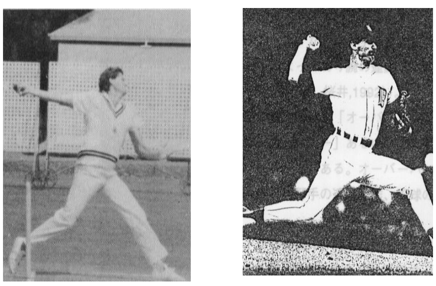


Figure 1: Cricket bowling and baseball pitching.

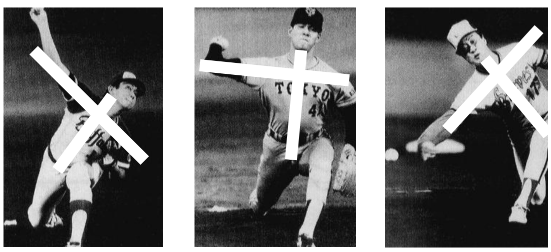


Figure 2: Overhand, sidehand, and underhand.

the pitcher's or bowler's action is strictly regulated. However, fielders who have no restrictions on their motion usually throw a ball with an overhand motion. Overhand throwing is a motion with which we can throw fastest and most accurately.
We could define "overhand throwing" as the motion of thrusting an object into space by the use of one arm with extension of the elbow and internal rotation of the shoulder as major upper limb actions, and with which the upperarm is kept apart from trunk.

WHY ARE WE ENCHANTED BY THE MOTION OF "OVERHAND THROWING"?

Man cannot fly, run faster than cheetah; jump longer than kangaroo or swim faster than a dolphin. But we can throw farther, stronger, and better than any other animal (Figure 3). Some anthropoids such as chimpanzees and gorillas are known to throw, but their motion is mainly underhand.

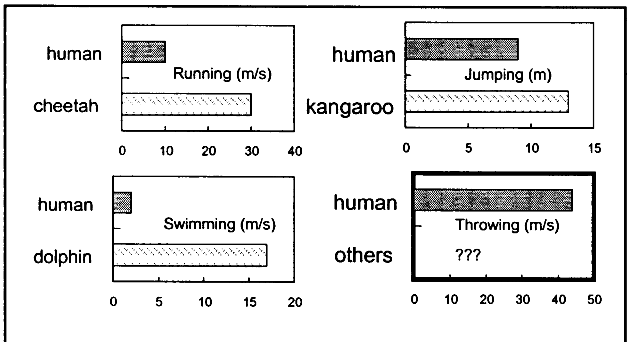


Figure 3: Comparison of the human ability with other animals

We are very weak creatures, and our physical ability is very limited. But throwing is one given-talent. Only humans can throw. In more accurate sense, man is the only creature who can throw with an overhand motion.
The most effective method to study how genetic and environmental factors affect development and growth is through the study of twins. In running and jumping movements, techniques of identical twins were generally similar to each other (Goya et al., 1988; Fukashiro et al., 1985), while Toyoshima et al. (1982, 1983) found that the similarity of the throwing motion between two sets of twins were low. Motions such as walking and running are often discussed as ontogenic, while throwing is regarded as a phylogenic motion. These findings suggest that the throwing motion is more highly affected by environmental factors, such as learning and practice.

HOW HAS THROWING MOTION BEEN STUDIED?

Throwing has attracted much researcher interest, and it has been studied with a variety of methods.
Speed changes of the body parts were reported in many papers, and the contribution of the whip-like body actions and the effect of the stretch-shortening cycle were discussed in relation to the thrown ball velocities. Miyashita et al. (1986) compared the horizontal velocity changes of various body parts and reported the period in which velocity change of body centre of mass exceeded that of the throwing hand. They suggested there was every possibility of the reutilization of the stored elastic energy increasing the ball speed.
Both kinematic and kinetic aspects of throwing have also been studied.
Toyoshima and Miyashita (1973) studied the relationship between ball speed and force applied to the ball during the throwing motion for balls of the same size (diameter=7cm) and nine different weights (100g to 500g). Ishii and Nakade (1974) studied the changes in force applied on the ball during the throwing motion for speed of male handball players with balls of six different weights ranging from 180g to 900g (diameter=18.5cm). The force and the mechanical work exerted on the ball increased as the ball increased in weight. Almost all of the mechanical energy of the ball at release was supplied in the very short period just before release.

Toyoshima et al. (1974) investigated contribution of each body segment contribution to ball speed by restricting the motion of body segments involved in the throwing motion. They found without stepping or trunk rotation the ball was accelerated to only 50% of that attained in the normal throwing motion. They suggested this demonstrated the importance of muscles on lower limbs and trunk in throwing motion.

However, most of the research works were conducted in two dimensions, due to the restriction of the image analysis procedures available, although the three-dimensional (3-D) nature of the overhand throwing motion was well documented and recognized. Even in the case in which two or more cameras were used, the treatment of the data analysis was not quantitatively in 3-D space. For example, Toyoshima et al. (1976) filmed the throwing motions of various types of balls with two high-speed cameras set above and lateral to the subjects. Film analysis revealed the hip and shoulder rotation in the horizontal plane, however, they reported very little quantitative data on the throwing arm action.

Feltner and Dapena (1986) analyzed the motion of throwing arm of baseball pitchers using DLT procedures and 3-D cinematography. Their study included both kinematic and kinetic analyses. Their study was as a turning point, followed by many 3-D studies on the motion of throwing arm.

WHAT IS A "GOOD" THROWING MOTION?

It is well known that there is a remarkable difference in throwing ability between males and females. The gender difference in the throwing ability is much more obvious compared to other motions, such as running and jumping. The tendency that males are superior to females in throwing ability appears at a pre-school age and increases with age until adult status. Sakurai et al. (1995) used 3-D cinematography to compare the joint angle kinematics of the throwing limb in the period up to the ball release for male and female students throwing a softball for a distance (average distance for male: 47.0 m, female: 22.6 m). This remarkable gender difference is considered to be primarily caused by skill differences.

The throwing arm has seven degrees of freedom of joint motion apart from the fingers; three at the shoulder, one at the elbow, one at the radio-ulnar, and two for the wrist. Following seven joint angle changes corresponding to all these degrees of freedom were obtained throughout the throwing motion.

J1 : horizontal abduction / horizontal adduction angle at the shoulder joint,
J2 : abduction / adduction angle at the shoulder joint,
J3 : internal rotation / external rotation angle at the shoulder joint,
J4 : flexion / extension angle at the elbow joint,
J5 : pronation / supination angle at the radio-ulnar joint (forearm),
J6 : radial flexion / ulnar flexion angle at the wrist joint,
J7 : palmar flexion / dorsi flexion angle at the wrist joint.

Small sticks were fixed to the hand and forearm to permit rotations of the radioulnar and wrist joints to be calculated (Figure 4).

Major differences in joint angle changes between male and female subjects were found in shoulder motion (Figure 5). Male and female differed remarkably in the horizontal adduction / horizontal abduction angle of the shoulder. In the time period analyzed, the shoulder is more abducted horizontally for male compared to female throwers. Male subjects initially abducted the shoulder horizontally beyond a line

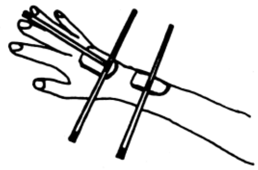


Figure 4:Small sticks for analysis of wrist motion.

connecting both shoulders, then adducted horizontally towards ball release. In contrast to the case of male, the mean value of the horizontal adduction angle for female subjects stayed positive indicating that the elbow was always in front of the shoulder alignment.

Though there was no statistic difference between adduction / abduction angles of shoulder between male and female subjects in the cocking phase, the shoulder was abducted and the upperarm was elevated for females in the acceleration phase, and the abduction angle for females was significantly larger than males at the ball release.

These results show the tendency that upperarm is raised in front of the trunk in unskilled throwing motion, while horizontal abduction followed by horizontal adduction in the horizontal plane is a major motion in a skilled throw.

Though the shoulder joint was rotated more externally for females than males in the cocking phase, the upperarm of the male was externally rotated rapidly and the absolute value of the external rotation of shoulder was larger than that for female group just before ball release. The extreme value of the external rotation angle for male group was -181.3 degree in average showing that the upperarm pointed almost directly posterior.

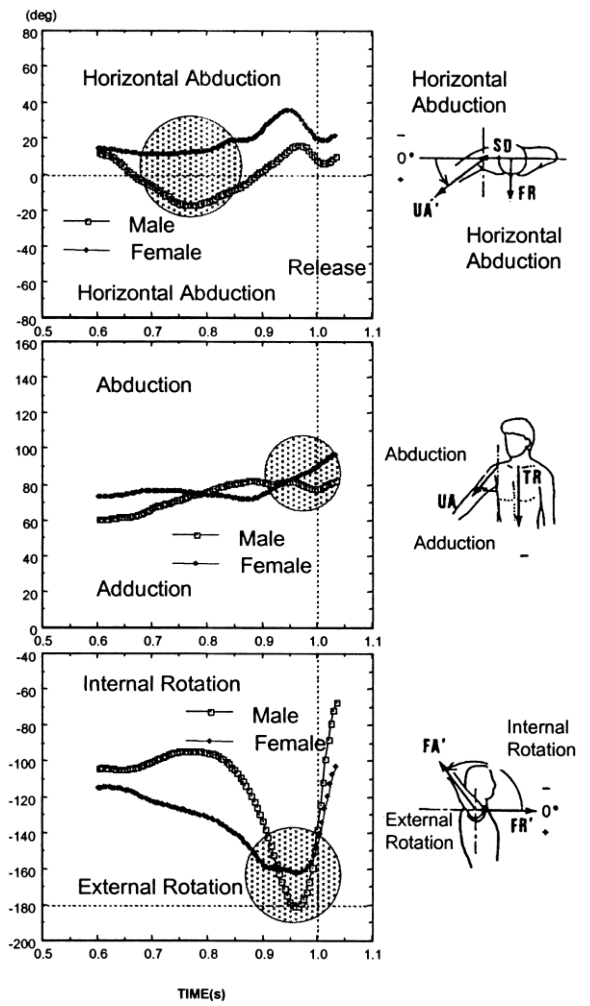


Figure5: Comparison of shoulder joint angle changes between male and female

In four-footed animals upperarm (and glenoid cavity) faces forward relative to the trunk, while it tends rather sideward in humans. Moreover human shoulder joint is considerably flexible because we do not need to support our body weight with the fore-limbs (arms). It might be said the skillful throwing motion of male subjects fully utilize the anatomical features of arms and shoulders of human being.

Sakurai et al. (1998) compared the developmental trend in throwing ability and throwing skills for children from six to eleven years of age in three countries with different social conditions (Australia, Japan, and Thailand). Girls were inferior to boys at all ages and in all countries, recording throwing distances of 51-67 % for those for boys. Throwing skills of girls compared also unfavorably with for boys in all groups. Thai boys and girls had inferior throwing ability and throwing skills when compared with Australian and Japanese children. The results suggested that the development of the throwing motion was highly affected by the direct and indirect involvement in sport events with throwing skills, such as baseball and cricket.

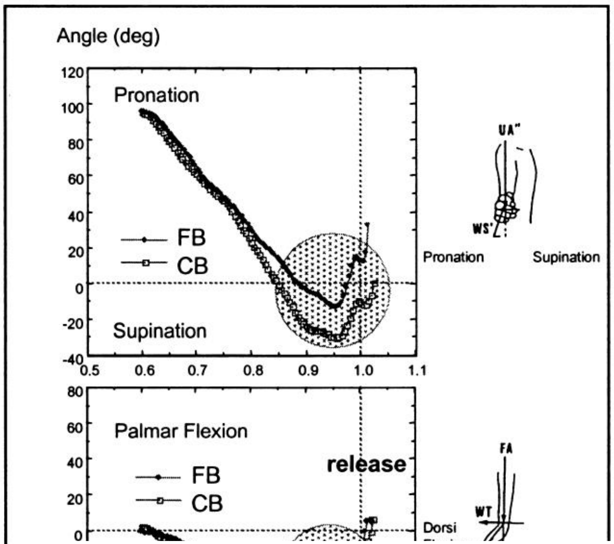
Cambell (1993) pointed out that most of the previous studies that have analyzed pitching mechanics have examined adult athletes, while little data have been presented quantitatively regarding the pitching mechanics of young athletes. Considering the throwing is not an ontogenic but rather a phylogenic motion, more thorough and longitudinal approaches on skill development and training effect would be expected with quantitative procedures.

HOW IS A CURVEBALL THROWN IN BASEBALL GAME? AND HOW IS IT DANGEROUS?

Curveball pitches in baseball have been thought to increase the risk of elbow injury, particularly if the athletes begin this pitch at an early age. Some writers have claimed that overstress of the flexor and pronator muscles attached to the medial epicondyle is caused by the forearm supination required in throwing a curveball (Atwater, 1979). However, Sisto et al. (1987) inferred that the curveball pitch was not as harmful as had been thought because there were no major differences in forearm muscle activity between fastball and curveball pitches. Very little quantitative data concerning the forearm and wrist action during throwing had been reported because a standard method of analysis was not established.

Joint angular kinematics of the throwing limb from the early-cocking phase to ball release were investigated for fastball and curveball baseball pitches using 3-D cinematography (Sakurai et al. 1993).

The actions were very similar for two pitches for one subject and there were no differences in the motions of the shoulder and elbow joints or in the temporal sequences between the two pitches. Though the forearm was more supinated at release in the curveball pitch than in the fastball pitch, the both pitches were characterized by pronation of the forearm just before and after release (Figure 6). The results therefore did not support the notion that the curveball pitch is more likely than the fastball to cause elbow injuries.



WHAT IS GOING ON?

Current status. Recently many 3-D studies have been executed focused on the motion of throwing arm from both a kinematic and kinetic perspective. Fleisig, G.S., Andrews, J.R., and the coworkers have been very enthusiastic in research on overhand throwing motion from the points of view both in performance enhancement and injury prevention. Here I would like to introduce several recent studies from Japanese researchers.

Matsuo et al. (1999) investigated the relationship between shoulder abduction angle at ball release and wrist speed and injury-related kinetic parameters on baseball pitchers using a computer

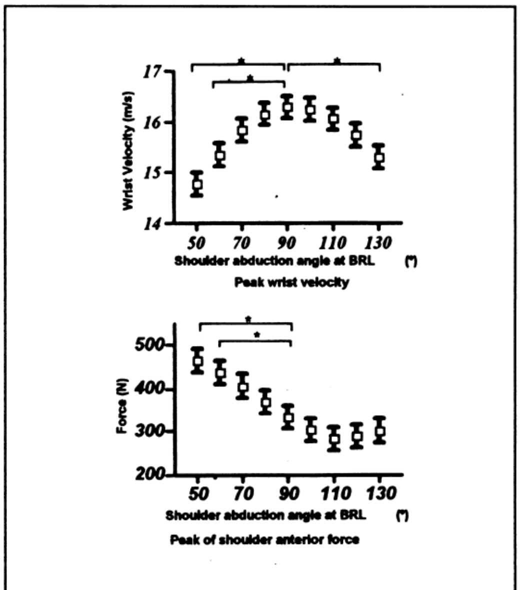


Figure 7: Influence of shoulder abduction angle on peak wrist velocity and shoulder joint kinetics

simulation. They modified shoulder abduction angle from the values in actual pitching and the influence on kinematic and kinetic parameters was obtained. Though the 90 degrees shoulder abduction angle at ball release maximized wrist velocity and decreased the elbow joint kinetics, it did not always minimize the shoulder joint kinetics (Figure 7).

Miyanishi et al. (1995) questioned modeling the trunk segment as one rigid body, and proposed a new model with two separate parts of a trunk, namely an upper torso and a lower torso. The angle changes of adduction/abduction of shoulder joint during baseball pitching were obtained based on the two modeling methods and shown in Figure 8. They found a certain difference in angular kinematics between two modeling methods. Though the shoulder appeared to abduct continuously with the modeling of a trunk as one segment, adduction was found with the two segments model of the trunk. They suggested the important role of the shoulder adduction during the throwing motion.

Takahashi et al. (1999) recorded the hand and finger movements (Figure 9) during baseball pitch using DLT procedures with high-speed videography (1000fps), and investigated their roles in increasing ball velocity. They revealed that the subjects who kept the fingers in more flexed position could accelerate the ball better in the final phase before ball release.

WHAT IS NECESSARY IN THE FUTURE?

Researchers suggest some of the future directions of biomechanical research of throwing movement, namely (1) computer simulation studies, (2) improvement or reformation of the modeling method especially on shoulder and trunk region, and (3) investigation into the movement and the role of the hand.

Though upperarm and forearm are rationally compared to solid segment, the region of trunk, shoulder, and hand are difficult to model as a single rigid body. In overhand throwing trunk and shoulder are both taking important role as a power generator, while the hand is also playing an important role in transmitting the momentum directly to the object. A complicated anatomical structure and fine movement skills enable us to throw skillfully. For the better understanding of the biomechanics of overhand throwing motion, a thorough study of the role of trunk, shoulder, and hand regions would be essential for both performance enhancement and injury prevention.

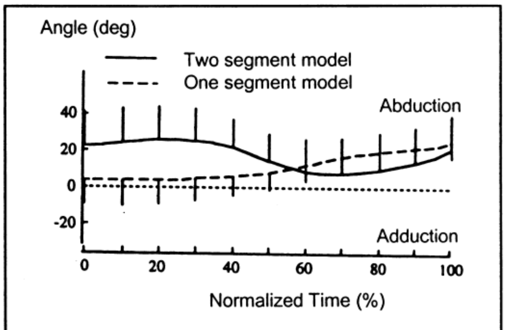


Figure 8: Comparison of shoulder abduction angle between two modeling methods of trunk

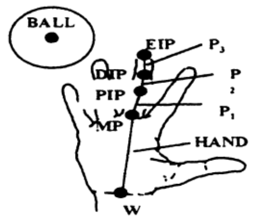


Figure 9: Model of hand.

CONCLUSION:

Past. Though throwing motion is often regarded as one of the basic motions along with walking, running, and jumping, the biomechanical studies on overhand throwing are few in number compared to other motions primarily because of the restriction of analytical procedures.

Present. Progress of the techniques of three-dimensional image analysis and kinematic and kinetic motion analysis on rigid body segment model, overhand throwing motion has been studied widely in recent years.

Future. Based on the results obtained in these analyses, research works with computer simulation would be more frequently executed. Considering the throwing is not an ontogenic but rather a phylogenic motion, more thorough and longitudinal approach on the aspects of skill development and practice effect would be expected. A thorough study of the role of trunk, shoulder, and hand regions are essential, and other techniques based on a musculo-skeletal modeling may also be necessary.

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