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The analysis of volleyball overhead pass

バレーボールのオーバーハンドパスの分析

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Contents

Chapter 1 .... *1*

1-1 Biomechanical research 1

1-2 The volleyball overhead pass 3

1-3 Stretch-shortening cycle 7

1-4 Kinetic chain 11

1-5 The purpose of the thesis 15

Chapter 2 .... *17*

2-1 Introduction 17

2-2 Methods 18

2-3 Results 29

2-4 Discussion 35

Chapter 3 .... *39*

3-1 Introduction 39

3-2 Methods 40

3-3 Results 47

3-4 Discussion 58

Chapter 4 .... *62*

4-1 Introduction 62

4-2 Methods 62

4-3 Results 65

4-4 Discussion 68

Chapter 5 .... *71*

5-1 SSC in overhead pass 72

5-2 The kinetic chain during overhead pass 74

5-3 Implications for coaching 76
5-4 Limitations 79
5-5 Conclusion 80
References *81*

Chapter 1

General Introduction

1-1 Biomechanical research

The history of kinematic research started in 19th century. Edward Muybridge (1830-1904) captured human locomotion movement (Figure 1-1), and found the characteristics of the movement which was not able to be seen by eyes (Muybridge, 1878). Since then the techniques of capturing human movements have advanced to a great deal and contributed much to the research on motor control (Baker, 2007). And the biomechanical research rapidly advanced also with the computer and technological innovation. Thirty years ago most researchers used cinematography to record human movement. In 10 years later the cinematography became obsolete and was replaced with videography. And now, digital and infrared videography have become the main tools for motion capturing. Thanks to the technology innovation, these temporal as well as spatial resolution of the kinematic analysis was improved much. While Muybridge could capture pictures only at twelve flames per second, researchers investigating human movements today utilize flame rates over 200 Hz which enables to analyze the very details of movement.

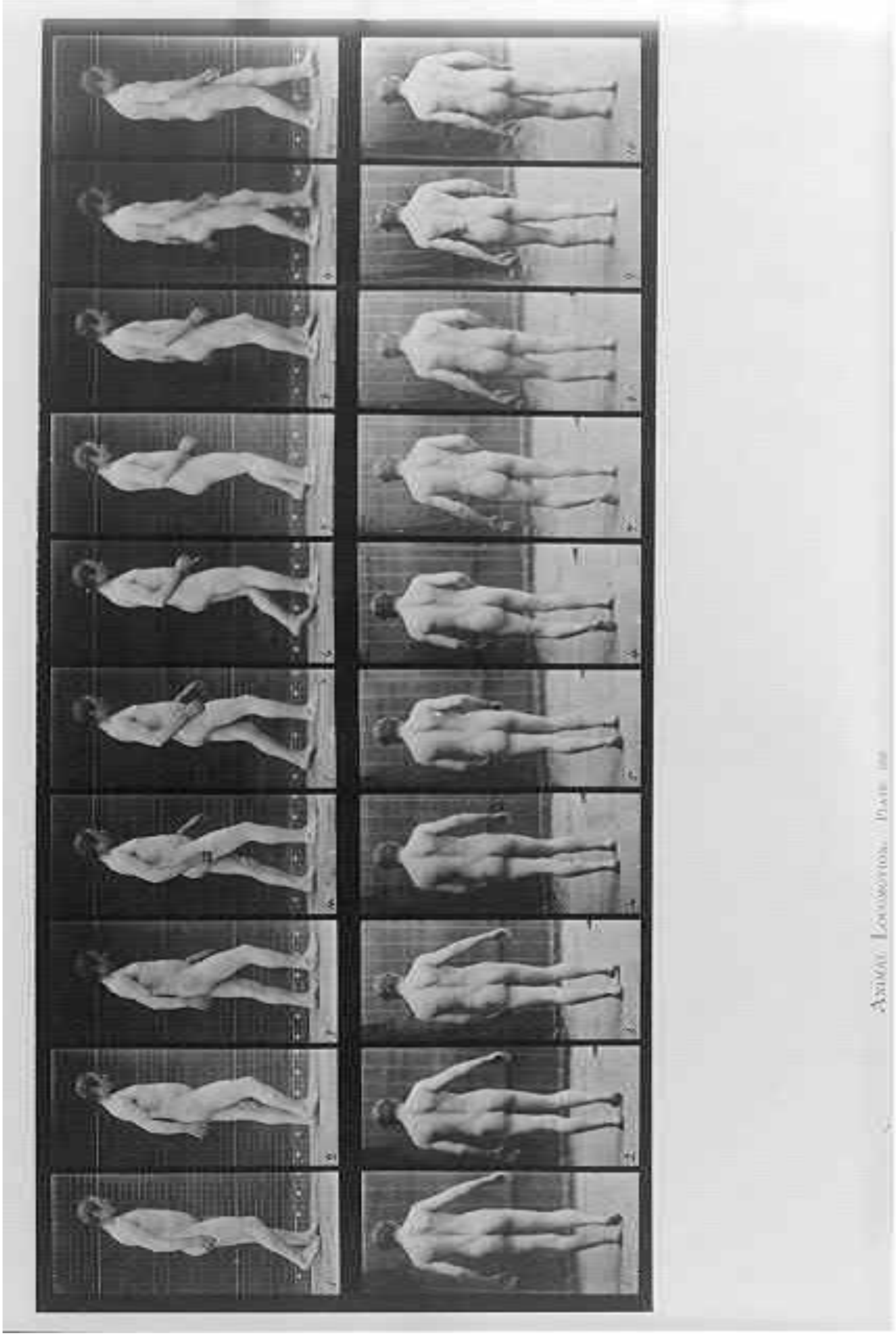


Figure 1-1 The series pictures of human walking. These pictures advanced the high-speed photography technology (Muybridge, 1878).

The inverse dynamics bridges the areas of kinematics and kinetics. According to Robertson et al (2013) inverse dynamics of human movement dates back to the seminal work of Wilhelm Braune and Otto Fischer in the period between 1895 and 1904 (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2013). These works were later revisited by Herbert Elftman with his research on walking (Elftman, 1939) and running (Elftman, 1940). From the kinetic investigation the efficient energy flow during the sports movement the important concepts such as "kinetic chain" have been established (Wagner et al., 2014).

1-2 The volleyball overhead pass

This thesis focuses on volleyball overhead pass. In volleyball game, the most important factor to win the game is attacking (Drikos, Kountouris, Laios, & Laios, 2009; Eom & Schutz, 1992), in which overhead pass is an indispensable skill, both for passing a ball and for setting a ball for spikers. Nikos, Karolina, & Elissavet (2009) showed that the higher the performance level of setters, the better the execution of attackers (Nikos, Karolina, & Elissavet, 2009). Fine motor control is required for the movement sequence of the overhead pass. In real games, positions and directions that players have to pass a ball change depending upon situations and the changes occur in a very short time.

Recently, offensive strategies of volleyball games have advanced a lot and the games became faster and more complex, so that faster and more precise setting is being required (Hughes & Daniel, 2003). In addition, due to this advance in attacking the reception (receive) has relatively became less accurate (Yiannis & Panagiotis, 2005); so the ball does not necessarily return accurately from a receiver to the setter, and setters are more required the ability to set a ball to attackers from variable position.

Figure 1-2 shows successive pictures of overhead pass. Catching is illegal in volleyball, and thus the overhead pass is not simple ‘grasping and throwing’. The average time of ball contact during an overhead pass is short, around 100 msec (Mary & Jerry, 1987; Ozawa, Uchiyama, Ogawara, Kanosue, & Yamada, 2019). Although an overhead pass does not require strong power, it is repeated many times in a game as well as training, so the pass should be as efficient as possible. So far the way to teach the skill of overhead pass is not necessarily evidence-based, because the overhead pass motion has not yet been analyzed, as compared with other volleyball motions such as spiking, jumping, and blocking were (Eom & Schutz, 1992; Ficklin, Lund, & Schipper, 2014; Hadzic, Sattler, Veselko, Markovic, & Dervisevic, 2014; Notarnicola et al., 2012).

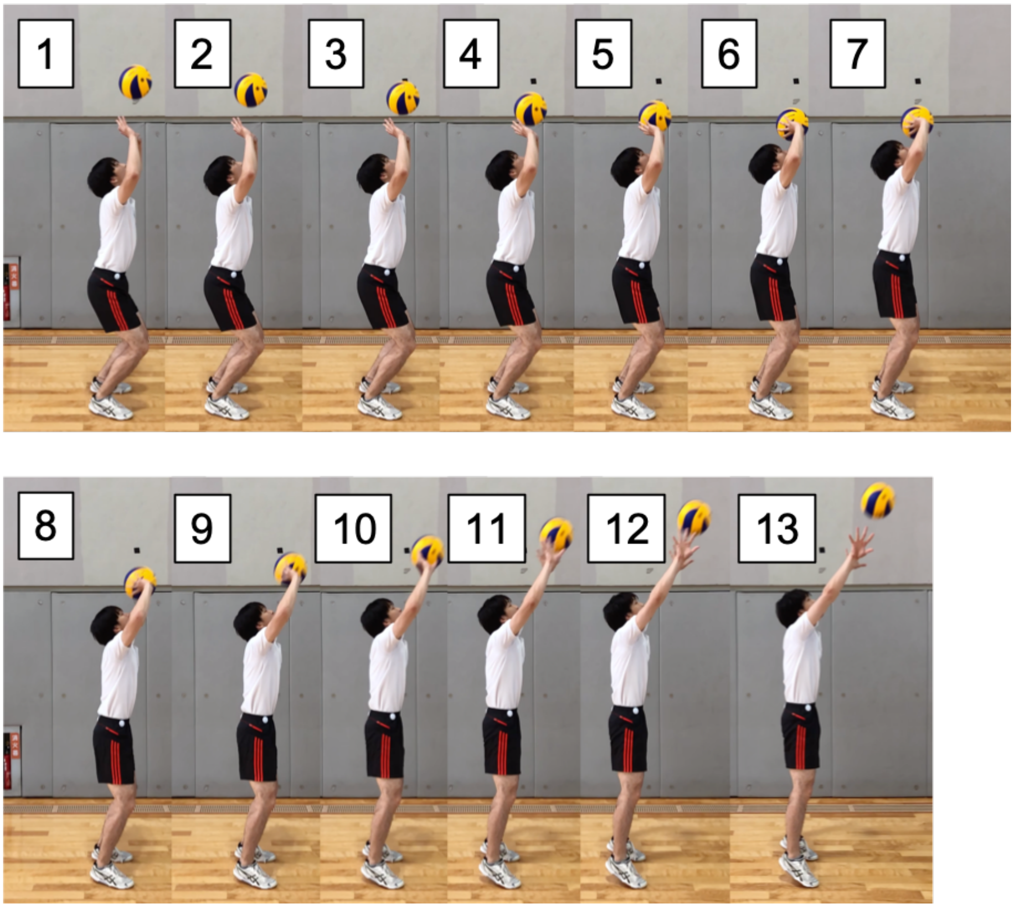


Figure 1-2 Successive pictures of overhead pass in volleyball. From 1 to 7 pictures were taken until the lowest ball position.

There are many biomechanical investigations of spiking (attacking). Wagner et al. (2009) suggested that the lowest position of the center of mass (COM) affected jump height. The "kinetic chain" were observed in the upper limb (from shoulder to finger) during the spiking motion (Coleman, Benham, & Northcott, 1993). When the hand contacted the ball the shoulder abduction angle was closed to 130 degree regardless of the spiking courses and serving types in volleyball players except roll shots which are covering (not hard) shots (Reeser, Fleisig, Bolt, & Ruan, 2010). Richards et al. (1996) concluded that not only large ground reaction force, but also such parameters as the high rate of knee extensor moment development, the angles of knee flexion at the time of landing, or the knee external moment during takeoff were significant predictors of patellar tendinitis (Richards, Ajemian, Wiley, & Zernicke, 1996). And according to Tilp et al. (2008), although the COM and leg joints movement of sand surface spiking jump in beach volleyball were significantly slower than that of wooden surface, the subjects tried to compensate the disadvantages of sand condition by altering their approach techniques such as shorter strides, flatter foot position (Tilp, Wagner, & Muller, 2008). As noted above, there are many researches of volleyball skills. However there is only one biomechanical analysis of overhead pass (Mary & Jerry, 1987), and it is only simple analysis of shoulder, elbow and wrist angles data. In coaching area, there is no common method way to teach the overhead pass skill. If the mechanism of an overhead pass were well described, it could provide players with a theoretical background which would aid in the development of this skillful motion.

1-3 Stretch-shortening cycle

When a muscle is eccentrically contracted before concentric contraction, the muscle can produce greater power than when there is only a concentric contraction (Cavagna, Saibene, & Margaria, 1965; G. A. Cavagna, Komarek, & Mazzoleni, 1971). This occurs because the elastic energy stored in the muscle and tendon during the eccentric contraction can be utilized (C Bosco et al., 1982; Masaki Ishikawa & Komi, 2004; Kawakami, Muraoka, Ito, Kanehisa, & Fukunaga, 2002; Norman & Komi, 1979; Padulo et al., 2013). This spring-like function of muscle and tendon is call as “stretch-shortening cycle (SSC)”.

Researches on the SSC have largely been done on high power movements such as sprinting (Carr, McMahon, & Comfort, 2015), and the jumping (Carmelo Bosco, Komi, & Ito, 1981; Hassani et al., 2013; Masaki Ishikawa & Komi, 2004), and shown that utilization of the SSC in the calf and thigh muscles is an efficient way for producing explosive power (D. Baker & Nance, 1999; Carmelo Bosco et al., 1981). A large body of evidence showed the usefulness of the SSC in high power movements mostly in the lower limbs (Carr et al., 2015; Masaki Ishikawa & Komi, 2004; Masaki Ishikawa, Komi, Finni, & Kuitunen, 2006; Skurvydas, Dudoniene, Kalvėnas, & Zuoza, 2002; Suchomel, Sole, & Stone, 2016). For example, Levenez et al. (2013) suggested that after the training of drop jump, the performance was improved, and the muscle tendon unit (MTU) of gastrocnemius medialis was more stretched than before the training (Levenez et al., 2013). Likewise, Ishikawa et al. reported that when the height of drop in drop jump increased, the tendinous tissue was elongated more with less stretched fascicle (Masaki Ishikawa & Komi, 2004). Morse et al. (2008) suggested that when muscle-tendon unit stiffness increase, the SSC of performance increases (Morse, Degens, Seynnes, Maganaris, & Jones, 2008). And the tendon stiffness increases with the muscle stiffness increase (Leonard, Brown, Price, Queen, & Mikhailenok, 2004). However, there is no information on SSC the upper limbs and for low power movements accompanying fine motor skills like the overhead pass.

During the drop-jump, the elastic energy is stored in the triceps surae during the eccentric contraction in the landing phase (Levenez et al., 2013) by the dropped body mass and it is released in the jumping phase to produce ankle planter flexion. In the case of overhead pass, as noted above, the duration of movement is very short. Spring-like movement of wrist would be required, which is very similar to the ankle movement during drop jump. Especially, the pulling phase in which a dropping ball is decelerated (Figure 1-2) corresponds well to the landing phase of drop-jump. Therefore, the SSC would also be utilized in volleyball overhead pass.

In this thesis, it was analyzed whether or not the eccentric contraction occurred before concentric contraction during the overhead pass motion, which is the sign of stretch shortening cycle (utilization of elastic energy). According to Mary et al. (1987) the duration time of overhead pass is around 100 msec (Mary & Jerry, 1987). Thus, the sequence of utilizing the elastic energy during overhead pass would be even shorter.

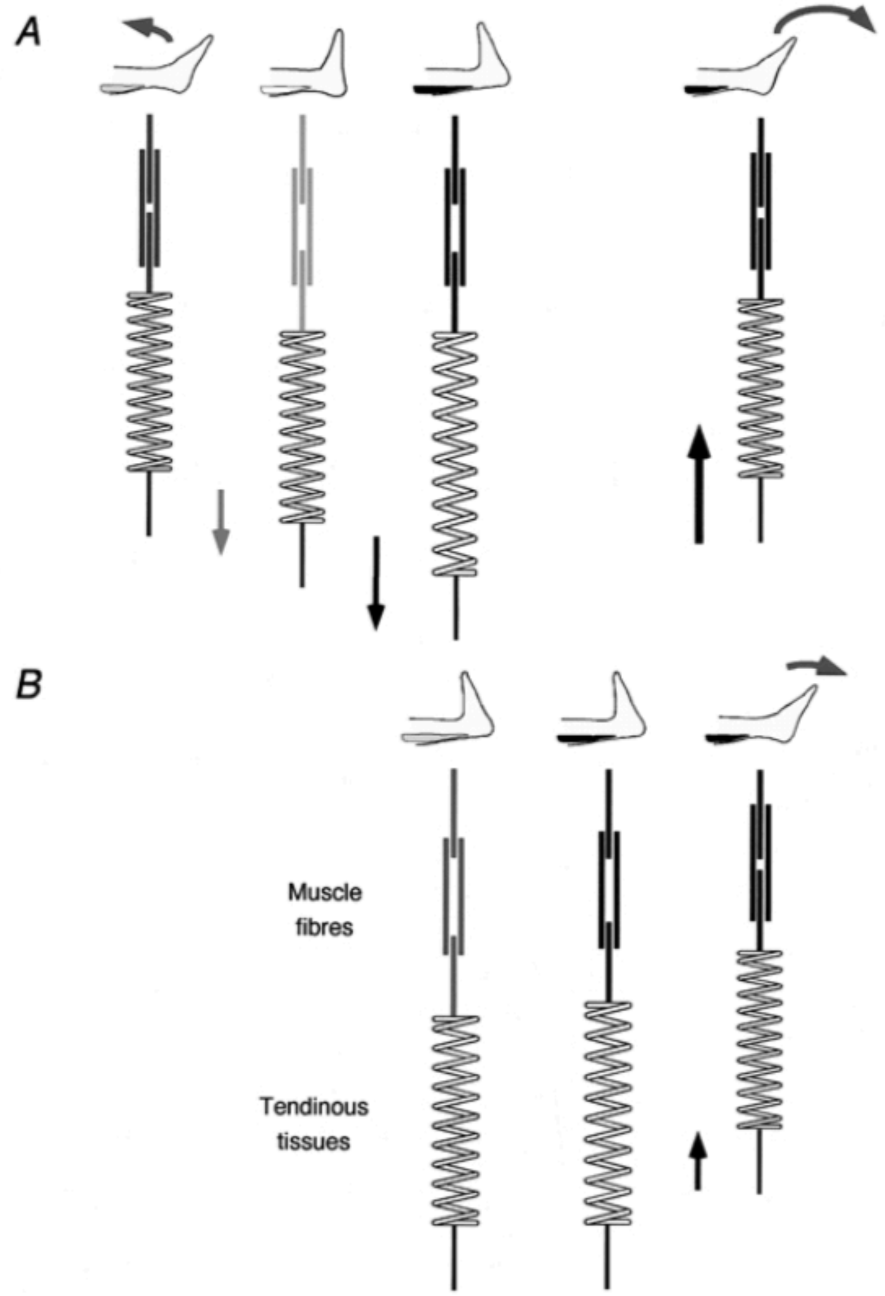


Figure 1-3 The Models of the MG MTU during the SSC exercises. The diagrams in A (counter movement) and B (no counter movement) illustrate the outline time course of changes in muscle tendon unit (MTU) from the onset through to the end of movement. When the line of muscle fiber is dark, the fibers are more active. In A, the MTU length increase during dorsiflexion phase, after the muscle fiber almost do not change when muscle is actively contracting (Kawakami et al., 2002).

1-4 Kinetic chain

Many movements in sports including volleyball spike shows a unique movement sequence of body parts called “kinetic chain” (Chapman & Sanderson, 1990; Serrien & Baeyens, 2017; Serrien, Clijsen, Blondeel, Goossens, & Baeyens, 2015; Yaghoubi, Esfehani, Hosseini, Alikhajeh, & Shultz, 2015). In the the proximal to distal pattern of muscle usage of kinetic chain a motion is initiated from the proximal larger and slowly rotating segments and propagates to the more distal segments, whose movement lags behind the proximal segment. Part of the mechanical nature of the kinetic chain is based on the Newton’s third law, conservation and transfer of momentum and energy. When the velocity of a proximal segment decreases, the deceleration causes an inertial effect, and the distal part is consequently accelerated. Wagner et al. (2014) showed that the team-handball throw, tennis serve, and volleyball spike have the order in the time of the maximal angular velocity from proximal to distal joints (Wagner et al., 2014).

The proximal reversal torque cause the counter torque for adjacent distal segment (Serrien & Baeyens, 2017). And the proximal movement also course the pre-stretching of adjacent distal joint muscles. An important biomechanical benefit involved in the kinetic chain is the SSC (Grezios, Gissis, Sotiropoulos, Nikolaidis, & Souglis, 2006; N. T. Roach, M. Venkadesan, M. J. Rainbow, & D. E. Lieberman, 2013).

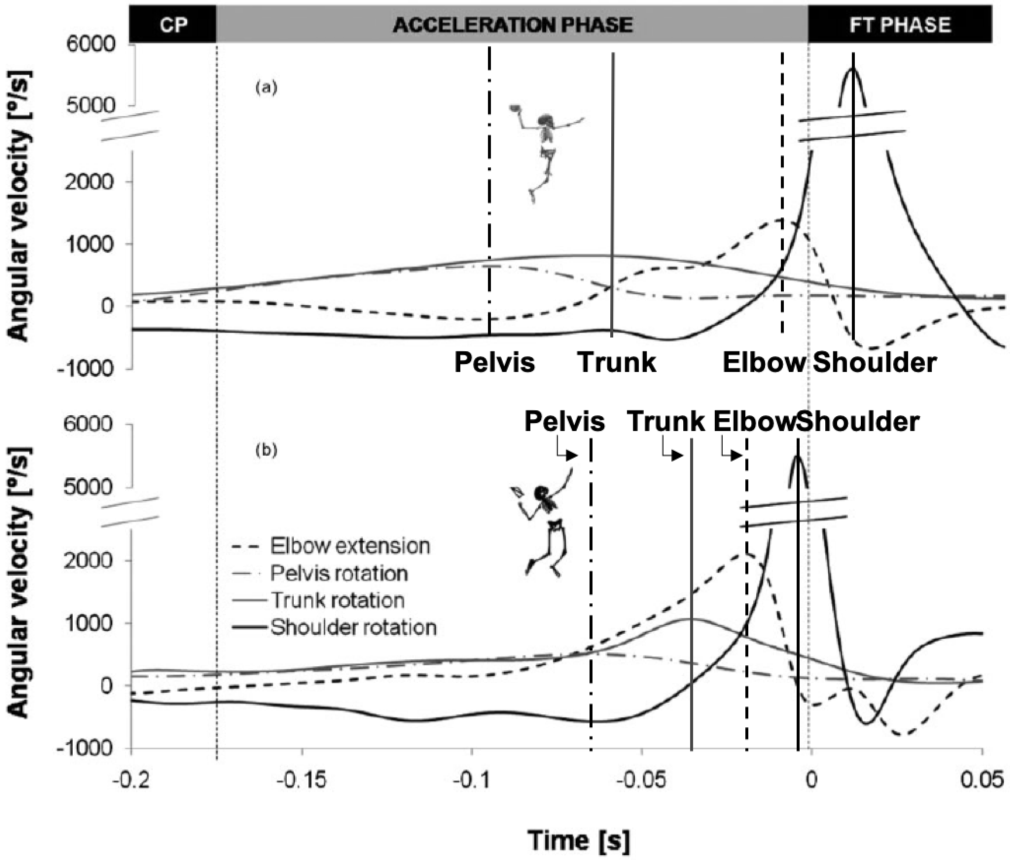


Figure 1-4 Example of kinematic chain in the team-handball throw (a) and tennis serve (b) both records include angular velocity of pelvis rotation, trunk rotation, elbow extension, and shoulder internal rotation. The ball release (a) and ball contact (b) was set at 0 sec. CP, cocking phase; FT, follow-through. Except shoulder rotation, the peak of the joint angular velocity appeared from proximal to distal joints (Wagner et al., 2014).

According to the van den Tillaar et al., (2013) in the study of the team-handball throwing, because the whip-like wind-up throwing is initiated with the greater shoulder external rotation angle which caused the greater elastic energy storage in the subscapularis tendon compared with the circular wind-up with more shoulder flexion and forward trunk tilt, the whip-like wind-up throwing would utilize the SSC more efficiently in the shoulder than circular wind-up (van den Tillaar, Zondag, & Cabri, 2013). During pitching, the pelvis and torso rotation which occurs prior to internal humeral rotation causes extension of the muscle and tendon around shoulder such as pectoralis major and anterior deltoid. Likewise, in baseball throwing elite pitchers the elastic energy produced at the shoulder during cocking phase, which is stored and released elastically, accounted 54 ± 15% of the internal humeral rotation work (Neil T Roach, Madhusudhan Venkadesan, Michael J Rainbow, & Daniel E Lieberman, 2013). This extension of muscle tendon unit produces elastic energy, for the subsequent explosive power transmitted to the brachium. Without a kinetic chain, the beneficial effects of the SSC could not be utilized because the joints movements which some joints move simultaneously would not cause the negative work to distal joints by proximal joint. The negative work efficiently store the elastic energy for MTU and ligament. The benefits of the kinetic chain are not only inertia energy flow from proximal segment to dorsi segment but also the SSC.

The kinetic chain is utilized in both throw-like motion and push-like motion such as punching (VencesBrito, Rodrigues Ferreira, Cortes, Fernandes, & Pezarat-Correia, 2011). In the volleyball overhead pass players push the ball with both arm. The kinetic chain would, thus, be working in overhead pass motion, but the detail biomechanical motion analysis of the movement has not been done. Mary, Ridgway, & Jerry (1987) analyzed the front and back setting of overhead pass movement, but only on motion range or mean angle during the main phase (Mary & Jerry, 1987). In this thesis, when the peak values appear from the proximal to distal joint in one sequence of overhead pass, the motion is recognized as a kinetic chain.

1-5 The purpose of the thesis

Many studies analyzed the human movements and muscle activities of sports, utilizing motion capture and electromyogram (EMG). Especially, the detailed information of sports movement would be useful to avoid the injury, and obtain better performances. In the present thesis, the volleyball overhead pass was analyzed by recording motion and EMG from the view points of the SSC and kinetic chain.

The purpose of this thesis is 1) to find the key technical point of the overhead pass skill by comparing the motions in skilled and unskilled subjects, and 2) to obtain how the distances of overhead pass is controlled in elite volleyball players by comparing movements of passing a ball to targets with different distances.

In **Chapter 2,** I analyzed the overhead pass to a middle distance by comparing the movements between skilled and unskilled subjects. From the difference between skilled and unskilled subjects, I discussed the important skill of overhead pass. I assumed that the important skill was mainly related to the movement of the upper arm when passing the ball to the middle distance, so the motion and EMG were captured from the upper arm. In **Chapter 3**, I will compare the overhead pass motions and muscle activities of skillful volleyball players among three different target distances. For the overhead pass of long distance, the legs movement would be more important so that will capture lower limb as well as upper arm movements. In **Chapter 4**, to verify results of Chapter 2 and 3 in the real game I will analyze the world competition of the volleyball. In **Chapter 5**, general discussion will be made from the results of Chapter 2, 3 and 4.

Chapter 2

Biomechanical analysis of overhead pass

2-1 Introduction

In sports motion previous studies compared motions, with various paradigms (e.g. with and without counter movement, trained and untrained group) to understand the important skill (Bobbert, Mackay, Schinkelshoek, Huijing, & van Ingen Schenau, 1986; Chaouachi, Othman, Hammami, Drinkwater, & Behm, 2014; Chelly, Hermassi, Aouadi, & Shephard, 2014; Hirayama et al., 2017; Janssen, Steele, Munro, & Brown, 2015). In these researches the tendon function was observed from the difference of tendon behavior between groups. In relation to volleyball, there are many studies which analyzed spike (attack) jumping (Pérez-Turpín et al., 2014), landing (Richards et al., 1996), or blocking movement(Ficklin et al., 2014). However, there was no research on overhead pass, the most basic and important skill in volleyball.

Currently, the way to teach the skill of overhead pass is not necessarily evidence-based, because the overhead pass motion has not yet been analyzed. If the mechanism of an overhead pass were well described, it could provide players with a theoretical background which would aid in the development of this skillful motion. So the purpose of this chapter is to obtain the mechanisms of the volleyball overhead pass technique, by comparing the motion between skill and unskilled subjects.

2-2 Methods

Participants

Twenty male participants participated in this study. Their characteristics are shown in Table 2-1. Half of them were top level university volleyball players (skilled). The other half had no experience with volleyball (unskilled). All of them were right handed according to the Edinburgh Inventory (Oldfield, 1971). In accordance with the Declaration of Helsinki, the experimental procedure was explained to all participants and each participant signed a written informed consent. The study was approved by the ethics committee of Tokai University.

Procedure

Participants were first told to do a warm-up at their own pace, This included performing some trials of the experimental task. Participants were told to stand still and then to pass a ball with an overhead pass through a ring (diameter: 1 m, height: 2.43 m) which was set 6 meters directly in front of them (Figure 2-1). A custom-made ball launching machine (Figure 2-3) located halfway between the target ring and the participant was used to supply the participant with a ball. In Figure 2-2 shows the picture of the experiment. If the propelled ball missed the ring, the trial was not included in the biomechanical analysis. Participants repeated the attempts until they succeeded in passing a ball through the ring. The number of trials required for success was utilized as an index of performance.

Table 2-1 Characteristics of subjects and number of attempts.
The position: L, Libero; MB, Middle Blocker; S, Setter; and WS, Wing Spiker. *, significantly lower than the unskilled group (*P* < 0.001).

Skilled

Subject I.D.	Height (cm)	Weight (kg)	Age (Years)	Years of experiment and Position		Number of attempts
A	162.4	58.2	21	11	L	2
B	163.1	56.7	19	8	L	4
C	170.2	68.5	20	13	L	3
D	165.1	70.0	21	13	L	2
E	186.6	69.7	20	11	MB	1
F	178.4	73.1	19	13	S	2
G	181.3	74.6	20	9	S	1
H	186.6	82.5	20	11	S	1
I	185.7	81.9	19	12	S	2
J	177.6	72.4	19	10	WS	1
Average ± S.D.	175.7±9.8	70.8±8.5	19.8±0.79	11.1±1.73		1.9±1.0*

Unskilled

Subject I.D.	Height (cm)	Weight (kg)	Age (Years)	Years of experiment and Position	Number of attempts
K	175.2	71.1	23	-	5
L	165.2	56.2	21	-	13
M	176.3	70.2	22	-	6
N	168.6	61.5	22	-	9
O	180.0	66.2	23	-	8
P	168.3	58.8	24	-	4
Q	160.3	62.4	22	-	6
R	163.5	76.2	23	-	10
S	172.8	68.4	23	-	7
T	180.2	98.4	23	-	13
Average ± S.D.	171.0 ± 6.9	68.9±12.0	22.6±0.8	-	8.1±3.1

Measurements

Sixteen reflective markers were placed on the participant in order to calculate joint center and joints angles. The positions of markers on the body were: shoulder (acrominon） ×2, upper arm (between the shoulder and elbow for offset) ×2, elbow (humeral lateral epicondyle and medial epicondyle) ×4, forearm (the place between the elbow and wrist for offset) ×2, wrist (styloid process of radius and ulna) ×4, and hand (the third metacarpophalangeal joint of the hands) ×2. Five reflective markers on the ball were attached and four them were used to calculate the ball center; the remaining one was used for offset. The four ball markers were decided by utilizing two pairs of two points forming a line segment passing through the volleyball center. And the offset marker was utilized for filling of gap markers and identifing all the other markers. So the offset marker was not utilized for calculating the ball center and it placed on asymmetrical place on the ball. A three-dimensional automatic digitizing system (Mac3D, Motion Analysis Co., USA; 10 cameras, sampling frequency: 250 Hz, shutter speed: 1/500 sec) was used to quantify motion of each point. The global coordinate system was determined with X, Y and Z axes, where the X axis was directed from the participant to the target, the Y axis was at a right angle in the horizontal plane, and the Z axis denoted the vertical direction.

A Butterworth low-pass filter set at 10 Hz was used to remove high frequency random interference on marker positions. Angular velocities were calculated by differentiating the involved angles.

The elbow and wrist joint angles (θ) were obtained by the dot product. For the elbow joint, vector *x* was that from the elbow to the shoulder, and vector *y* was that from the elbow to the wrist. For the wrist joint, vector *x* was from the wrist to the elbow, and vector *y* was from the wrist to the hand. Where the wrist angle was greater than 180 degrees, the location was determined by observing the data. The angles were expressed mathematically as :

$$\theta = arccos\left(\frac{\vec{x} \cdot \vec{y}}{|\vec{x}|\,|\vec{y}|}\right)$$

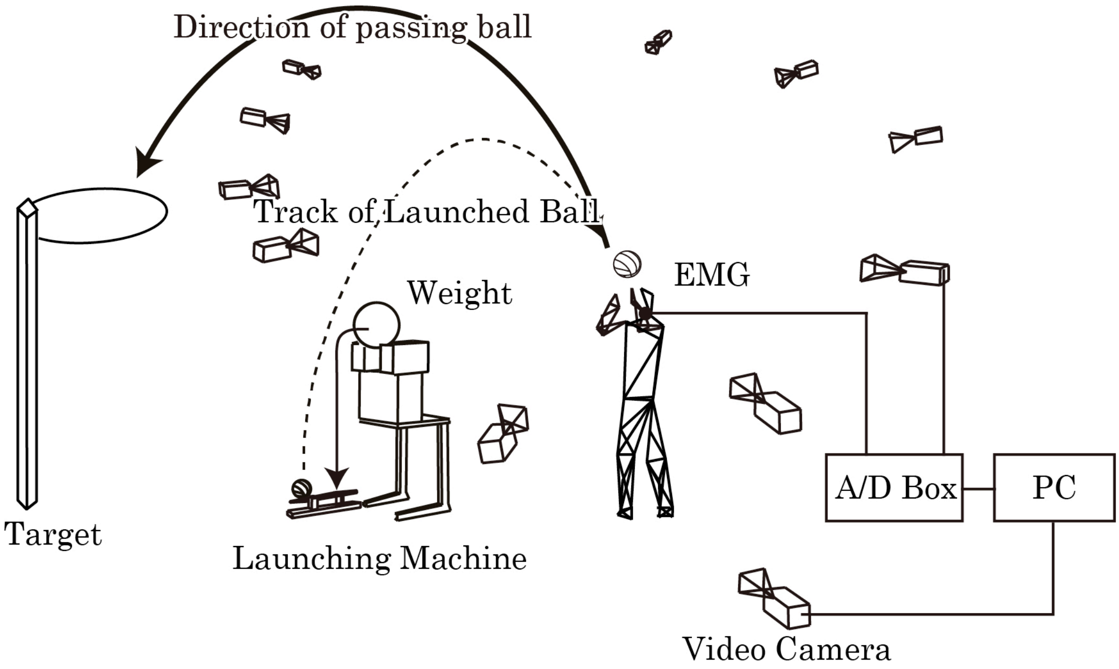


Figure 2-1 Outline of experiment

Above the subject are the capture cameras and the camera under the subject is the reference camera. The broken arrow is the track of the launched ball to the subject, and the solid arrow is the direction of the ball passed by the subject.

Figure 2-2 The picture of experiment

Electromyogram

We collected electromyographic (EMG) data from the a number of surface muscles on the right arm; Biceps Brachii (BB), Triceps Brachii (TB), Flexor Carpi Radialis (FCR), and Extensor Carpi Ulnalis (ECU). The recording from each area was accomplished with a wired bipolar electrode set (DL-141, S&ME Company, Japan) with a 12 mm separation. Sampling frequency for the EMG recordings was 1000Hz. Before attaching the electrodes, the skin was shaved and scrubbed to make a good electrical connection and to minimize the introduction of noise. Motion and EMG data were fed into a personal computer (Endeavor, EPSON Company, Japan) and could be synchronized using a known constant delay. At the end of each experimental session we recorded EMG data for more than 3 sec isometric maximum voluntary contraction (MVC).

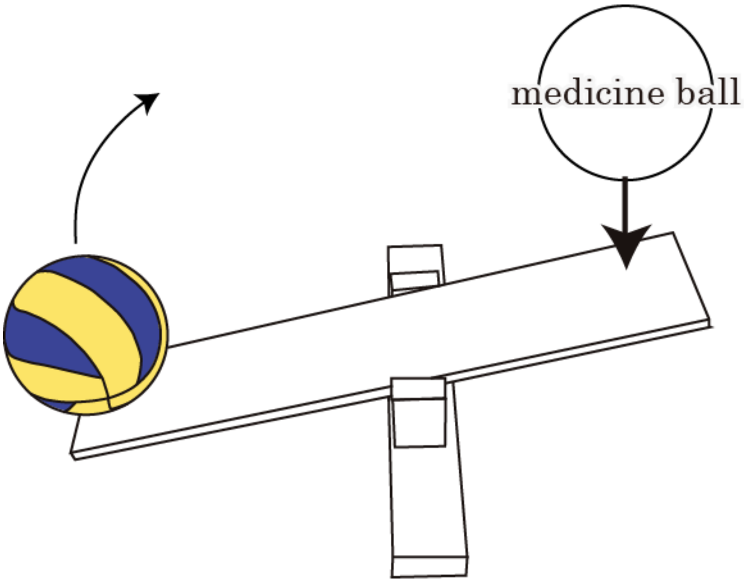


Figure 2-3 Ball launching machine

The board rapidly rotate by dropped the medicine ball. The ball was launch to the right direction by the board.

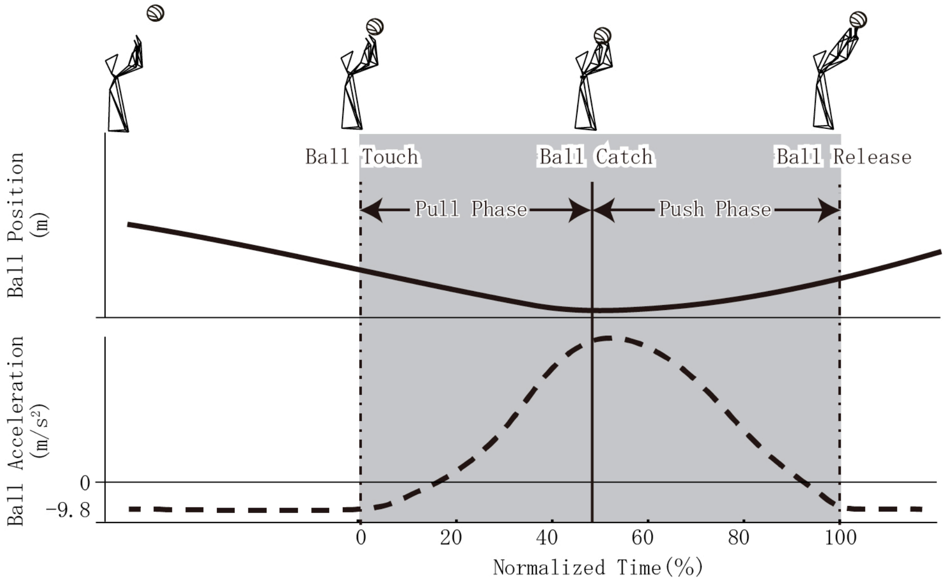


Figure 2-4 Definition of pull and push phase

The solid and broken lines are ball position (above) and ball acceleration (below). The shaded zone is the main phase. “Ball Touch” and “Ball Relaese” are defined as the moment when ball acceleration started to increase from, and returned to -9.8 (m/s^2), respectively. “Ball Catch”is the moment when the ball position was the lowest

Data Analysis

Division of phases

The main phase of passing action was defined as the period from ball touch to ball release. Ball touch and release were detected from tracking data of the ball. First, ball acceleration in the Z axis was obtained. The time of ball touch was defined as when the acceleration started to change from -9.8 m/s^2. Ball release was defined as when the acceleration returned to -9.8 m/s^2. The main phase of the overhead pass motion was further divided into pull and push phases as defined. ‘Ball catch’, defined as the point when the ball was at its lowest position in the main phase, divides the pull and push phases. The duration of the main phase was standardized as 100 % to compare motions in the skilled and unskilled groups (Figure 2-2).

The calculation of Electromyogram

EMG data were passed through a Butterworth band-pass-filter with a 10-500 Hz bandwidth in order to remove high frequency random interference and motion artifacts of low frequency. The signal was then rectified. The EMG data for each muscle was standardized as %EMG using the value of the MVC. This can be expressed mathematically as:

$$\%\mathrm{EMG} = \frac{\mathrm{EMG_t}}{\mathrm{EMG_{MVC}}}\ [\%],$$

where EMC_t is the EMG data at time t, and EMG_{MVC} is the averaged MVC EMG over the 3 sec period according to Philipou et al. (2009).

Then, we calculated the percent root mean square value (%RMS); this value has been related to constant force for a non-fatiguing contraction (Phinyomark, Hirunviriya, Limsakul, & Phukpattaranont, 2010) . %RMS is expressed as:

$$\%\mathrm{RMS} = \sqrt{\frac{1}{t}\int_0^t \%\mathrm{EMG}_t^2(t)dt} .$$

The actual calculations were performed using Mathematica (Wolfram, America).

Data in skilled and unskilled groups were compared with unpaired nonparametric Mann-Whitney test. Right and left arms angle and angular velocity were compared using Two-way repeated measures analysis of variance. The significant level was at $p < 0.05$.

2-3 Results

The average number of trials that the skilled group took to succeed in passing a ball into the ring was significantly lower than that of the unskilled group (Table 2-1, $p = 0.00001$). There was no significant difference in height between skilled and unskilled groups ($p = 0.234$) while 4 skilled participants succeeded in the first trial, no unskilled participant accomplished this. The duration of the main phase between all the participants was 87 ± 23 msec and was not statistically different for the skilled and unskilled groups. The timing of 'ball catch' (48 ± 7 %) in main phase was also not statistically different between the two groups. There was no significant difference between angles and angular velocities of right and left arms in the main phase.

Figure 2-3 depicts typical examples of the raw-data for joint movement and EMG activity during an overhead pass for a skilled and an unskilled participant. Figure 2-4 shows group data for elbow angular velocity and angle as well as for activity of the BB and TB, and in the main phase. There was no significant difference in elbow angle between skilled and unskilled groups (Figure 2-4A). At the start of the main phase, angular velocity has a positive values in both groups (Figure 2-4A). This indicates that when the ball touched the participant's hands the elbow had already started to extend.

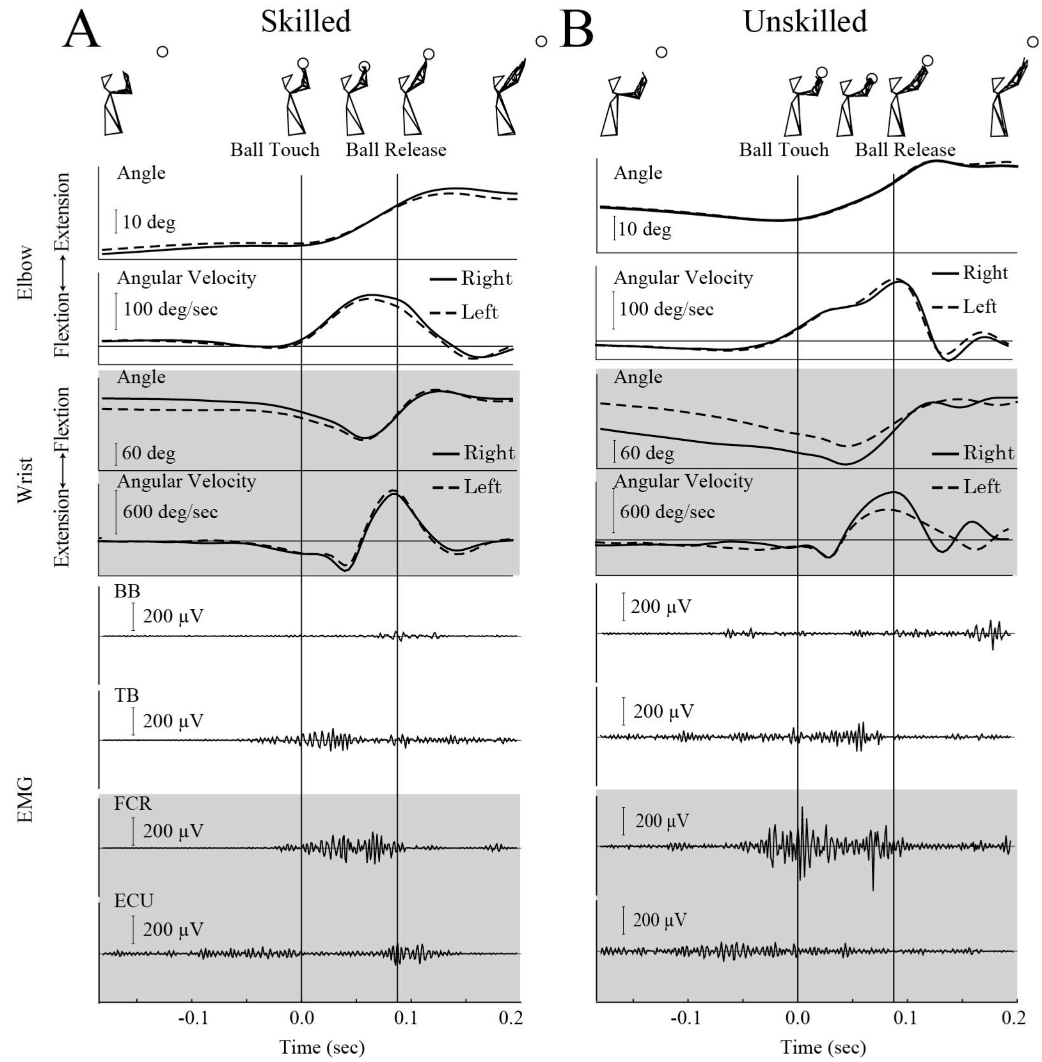


Figure 2-5 Typical raw data

Typical raw data of changes in joint angles and EMGs for a skilled participant (A) and an unskilled participant (B). In motion recordings the solid lines show the right arm data, and broken lines show the left arm data. The vertical lines shows ball touch (left) and ball release (right). The data of wrist are shaded. BB: Biceps Brachii, TB: Triceps Brachii, FCR: Flexor Carpi Radialis ECU: Extensor Carpi Ulnalis.

There was no significant difference in elbow joint angle between left and right arms. There was also no significant difference in wrist angle between skilled and unskilled groups. In the skilled group the angular velocity had a peak at 60~80 % of the normalized time, while in the unskilled group the angular velocity continued to increase during the entire main phase. The rate of the increase for the unskilled group did slow down in the push phase. In the pull phase, the magnitude of TB activity was large for both groups (47 ± 27 %), while BB activity was small for both (4 ± 3 %, Figure 2-4B). There was no statistical difference between the groups for either TB or BB activity in the pull phase. During the push phase, TB activity in the skilled group (16 ± 10 %) was significantly lower than that of the unskilled group (31 ± 12 %, Figure 2-4C, $p = 0.009$).

Figure 2-5 shows group data for wrist angular velocity, and activities of the FCR and ECU in the main phase. There was no significant difference in wrist joint angle between left and right arms. There was also no significant difference in wrist angle between skilled and unskilled groups (Figure 2-5A). Both groups had already started to extend the wrist when the ball touched the participants' hands (Figure 2-5A). Before ball catch, the wrist joint angle remained extended, and after the ball catch the movement changed from extension to flexion at around 60 % of the normalized time (Figure 2-5A). The FCR had high activity in the pull phase for both groups (Figure 2-

5B). FCR activity in the skilled group was significantly higher than in the unskilled group (Figure 2-5B, skilled: 53 %, unskilled: 34%, $p = 0.028$). ECU activity did not differ between both groups in the pull phase nor in the push phase.

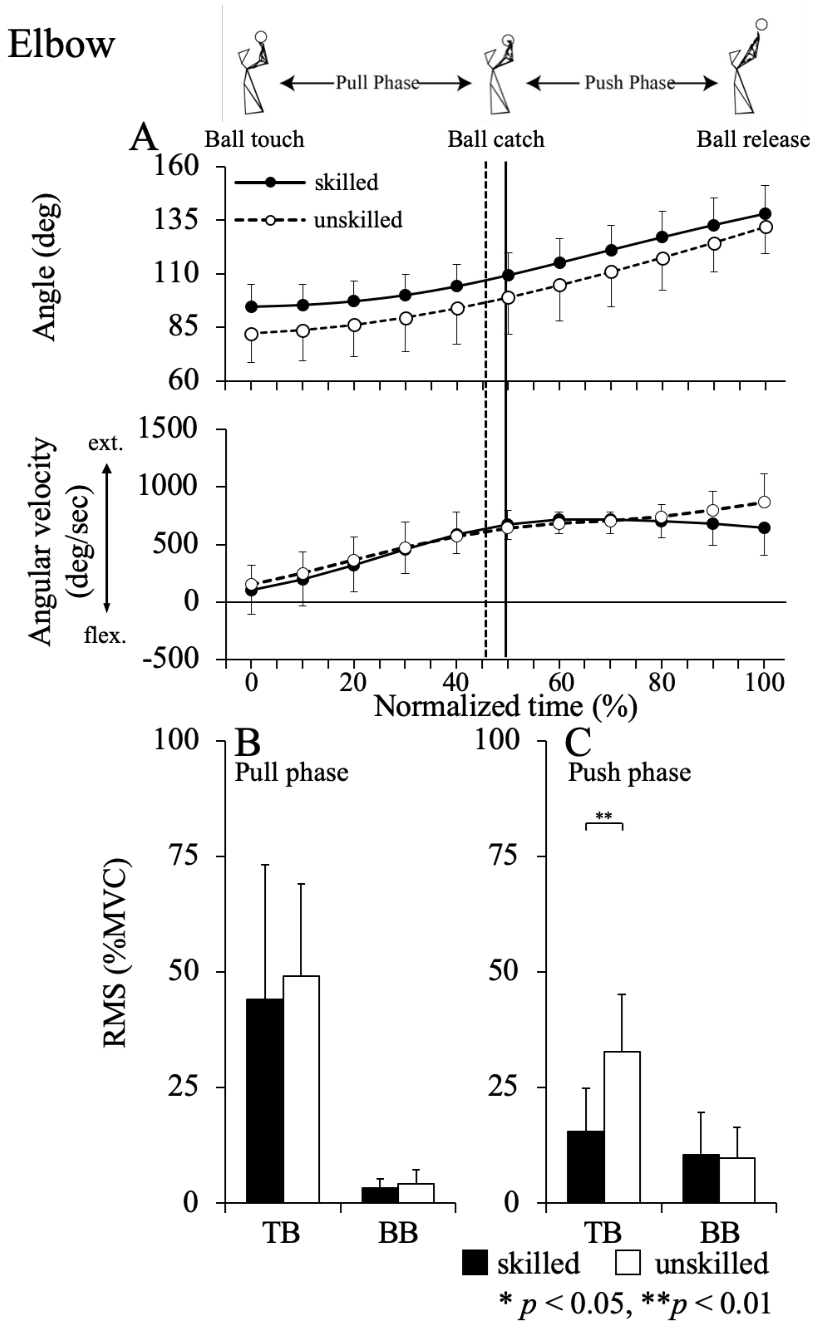


Figure 2-6 Motion and EMG activity of elbow

Graph A: shows elbow angle and angular velocity data against means normalized time in the main phase. The solid lines and closed circles are the skilled group and the broken lines and open circles are the unskilled group. Solid and broken vertical lines are the mean times of ball catch, in the skilled and the unskilled groups, respectively. B and C: activities of BB and TB in the pull phase (B), and in the push phase (C). The black and white bars show skilled and unskilled groups, respectively.

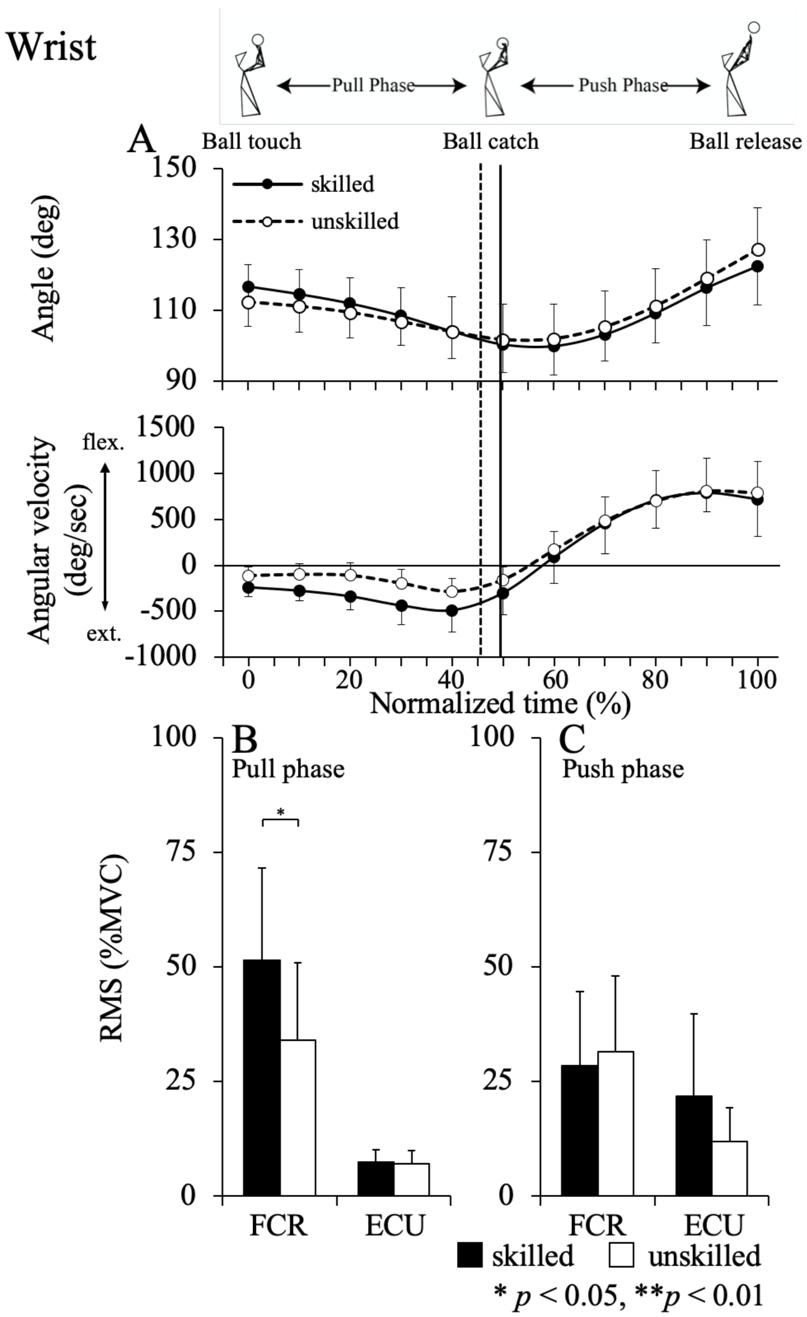


Figure 2-7 Motion and EMG activity of wrist

Graph A: shows wrist angle and angular velocity data against means normalized time in the main phase. The solid lines and closed circles are the skilled group and the broken lines and open circles are the unskilled group. Solid and broken vertical lines are the mean times of ball catch, in the skilled and the unskilled groups, respectively. B and C: activities of FCR and ECU in the pull phase (B), and in the push phase (C). The black and white bars show skilled and unskilled groups, respectively.

2-4 Discussion

Although an overhead pass is the standard method for ‘setting’ or passing a volleyball, it is an unique motion in that it does not involve a grasp (catch) and subsequent throw. A detailed biomechanical analysis of this important skill has not been done. The main purpose of the this chapter was to elucidate the movement sequences of this important skill and to use this information in an analysis of the biomechanical differences between skilled and unskilled participants.

The skilled participants were able to successfully ‘set’ a volleyball through a target ring with less attempts than were the unskilled participants (Table 2-1). Four of the skilled participants succeeded on the first attempt, while all unskilled participants needed from four to thirteen attempts to succeed. Clearly, the skilled participants were more proficient at the overhead pass than the unskilled ones. There was no significant difference between right and left arm movements in changes in angles and angular velocities in the main phase even in the unskilled group. Therefore, the symmetry of movement and EMG activity was likely to be maintained although EMG data was recorded from only right hand. There was also no significant differences in both wrist and elbow motion between skilled and unskilled groups. This would be because the analysis was made only for the succeeded trials in both groups, resulting in very similar ball trajectory, and does not indicate that there was no difference in the skill of overhead pass between the groups.

Motion and EMG during the pull phase

In the pull phase, the activity of FCR exhibited statistical differences between the skilled and unskilled groups (Figure 2-5C). Thus, there are likely to be some distinctive characteristics in the wrist function for the pull phase of the skilled participants. This result suggested that the wrist muscle stored the elastic energy during pull phase. On the other hand, there was no difference in the elbow motion nor in EMG in the pull phase (Figure 2-4A and B). Thus, during the pull phase both groups resisted to the dropped ball and pushed it by elbow extension in a similar way.

Although both skilled and unskilled subjects extended the wrist during the pull phase, the FCR showed a higher level of EMG activity than the ECU in both group (Figure 2-5A and B, 3-5A and B) That is, the FCR showed an eccentric contraction in this phase, and after the ball catch, the FCR switched to a concentric contraction. This indicates that in the overhead pass motion a stretch shortening cycle (SSC) functions in the FCR.

Motion and EMG during the push phase

In the push phase, there was no statistical significance between the groups in the motion of the elbow and wrist joints (Figure 2-4 and 5). However, a higher TB activity in the unskilled group (Figure 2-4C) indicates that they used the elbow joint more strongly than did the skilled group. On the other hand, the skilled group might have used to use the elastic energy of the FCR that was accumulated during the pull phase. This is an important overhead pass capability that the skilled group had developed. In a previous study, the activity of the gastrocnemius during the push off of drop jump in quick drop jump group was shown to be higher than slow drop jump group (Bobbert et al., 1986). The function of the wrist joint during the overhead pass is closed to that of the ankle joint during drop jump. The unskilled group would provide the supplementary energy needed for pushing the ball by elbow extension, since they could not accumulate sufficient elastic energy in the wrists. This would be reflected in the fact that TB activity was greater in the push phase in the unskilled group than the skilled group (Figure 2-4C).

Kinetic link in the overhead pass

Generally, for a skilled throw-like motion such as pitching (Seroyer et al., 2010), kicking (Chapman & Sanderson, 1990), and a push-like motion such as shot put (Čoh, Štuhec, & Supej, 2008), the peak velocity appears in the order from the proximal to the distal joints. This leads to an efficient energy flow, which has been termed the “kinetic chain” (Kreighbaum & Barthels, 1996). In this chapter, the peak angular velocity for elbow joint in the skilled group occurred at sixty to eighty percent of the normalized time, while the angular velocity in the unskilled group kept increasing until the end of the push phase (Figure 2-4A). On the other hand, wrist joint angular velocity peaked at ninety percent of normalized time for both groups (Figure 2-5A). Thus, while the skilled group demonstrated a kinetic chain-like order of peaks in angular velocity (first the elbow then the wrist) (Chapman & Sanderson, 1990), the unskilled group did not. This suggests that the unskilled participants did not utilize the kinetic chain, and would thus suffer an inevitable energy loss.

This chapter revealed that the skilled participants pushed the ball by wrist flexion with the SSC, but unskilled participants did that in a less degree because the FCR activity of skilled group in the pull phase was greater than unskilled group. When unskilled novices are coached for the overhead pass, the importance of the spring function of the wrist should be emphasized. For example, it would be effective to let unskilled novices practice the overhead pass with the elbows kept at the fully extended position so that they cannot use the elbow.

Chapter 3

Biomechanical analysis of distance adjustment in volleyball overhead pass

3-1 Introduction

In Chapter 2, skill to utilize the SSC in the wrist was shown to be important for the overhead pass. When performing an overhead pass in real games, it is necessary for players to control the appropriate distance of passing a ball, which changes from one shot to the other depending on situations (Hughes & Daniel, 2003). Although the biomechanical data concerning the control of the distances would be very useful for both players and coaches, so far no such data is available. The purpose of this chapter is to describe how the distances of overhead pass is controlled in elite volleyball players by comparing movements of passing a ball to a target with different distances. The first hypothesis was that the flexor muscle activity during the pull phase increases as the target distance increased. In the Chapter 2, the FCR activity of skilled group was greater than unskilled group, so the wrist muscle activity during pull phase would be important to control the distance in the overhead pass. In addition, elastic energy of the Triceps surae is stored in the eccentric phase (Levenez et al., 2013), the eccentric phase of overhead pass is the pull phase, so when SSC is more utilized, FCR during the pull phase would be increased in to pass longer distances.

From the view point of the kinetic chain, the coordinated movements between upper and lower limb would be necessary especially for the overhead pass of longer distance. In this chapter, the movement of overhead pass was investigated not only for upper limbs but also lower limbs. The second hypothesis was that the lower body movement became more important for longer distance pass.

3-2 Methods

Participants

Twelve male participants participated in this study. Their characteristics are shown in Table 3-1. All of them were top level university volleyball players, and right handed according to the Edinburgh Inventory (Oldfield, 1971). In accordance with the Declaration of Helsinki, the experimental procedure was explained to all participants and each participant signed a written informed consent. The study was approved by the ethics committee of Waseda University.

Procedure

Participants were first told to do a warm-up at their own pace, this included performing some trials of the experimental task. Participants were told to stand still and then to pass a ball with an overhead pass through a ring (diameter: 75 cm, height: 2.43 m) which was set 3, 6, and 9 meters directly in front of them (Figure 3-1). A custom-made ball launching machine located between the target ring and the participant was used to supply the participant with a ball. If the propelled ball missed the ring, the trial was not included in the biomechanical analysis. Participants repeated the attempts until they succeeded 5 times in passing a ball through the ring at each distance.

Table 3-1 Characteristics of subjects and number of attempts.
The position: L, Libero; MB, Middle Blocker; S, Setter; and WS, Wing Spiker.

	Height (cm)	Weight (kg)	Age (year)	Position	Experiment (year)
A	181	72	22	WS	14
B	176	69	22	WS	11
C	170	58	20	L	12
D	184	68	18	S	10
E	188	87	19	WS	13
F	186	74	19	WS	8
G	201	97	21	MB	7
H	188	71	19	WS	13
I	201	87	20	WS	7
J	196	85	20	MB	8
K	178	75	20	WS	12
L	184	74	18	WS	6
average	186±10	76±11	20±1		10±3

Measurements

Motion analysis

Nineteen reflective markers were placed on the participant in order to calculate joint center and joints angles. The positions of markers on the body were: anterior superior ilic spine (pelvice, ASIS) ×2, the center between the right and left posterior superior ilic spine (posterior pelvis, PSIS), anterior superior ilic pelvis shoulder (acrominon) ×2, upper arm (between the shoulder and elbow for offset)×2, elbow (humeral lateral epicondyle and medial epicondyle)×4, forearm (the place between the elbow and wrist for offset)×2, wrist (styloid process of radius and ulna)×4, and hand (the third metacarpophalangeal joint of the hands)×2. Five reflective markers on the ball were attached and four them were used to calculate the ball center; the remaining one was used for offset. The four ball markers were decided by utilizing two pairs of two points forming a line segment passing through the volleyball center. The fifth marker was offset marker. And the offset marker was utilised for filling of gap markers and identifing all the other markers. So the offset marker was not utilised for calculate the ball centre and it placed on asymmetrical place on the ball. A three-dimensional automatic digitising system (Mac3D, Motion Analysis Co., USA; 10 cameras, sampling frequency: 500 Hz, shutter speed: 1/1000 sec) was used to quantify motion of each point.

The global coordinate system was determined with X, Y and Z axes, where the X axis was directed from the participant to the target, the Y axis was at a right angle in the horizontal plane, and the Z axis denoted the vertical direction. A Butterworth low-pass filter set at 10 Hz was used to remove high frequency random interference on marker positions.

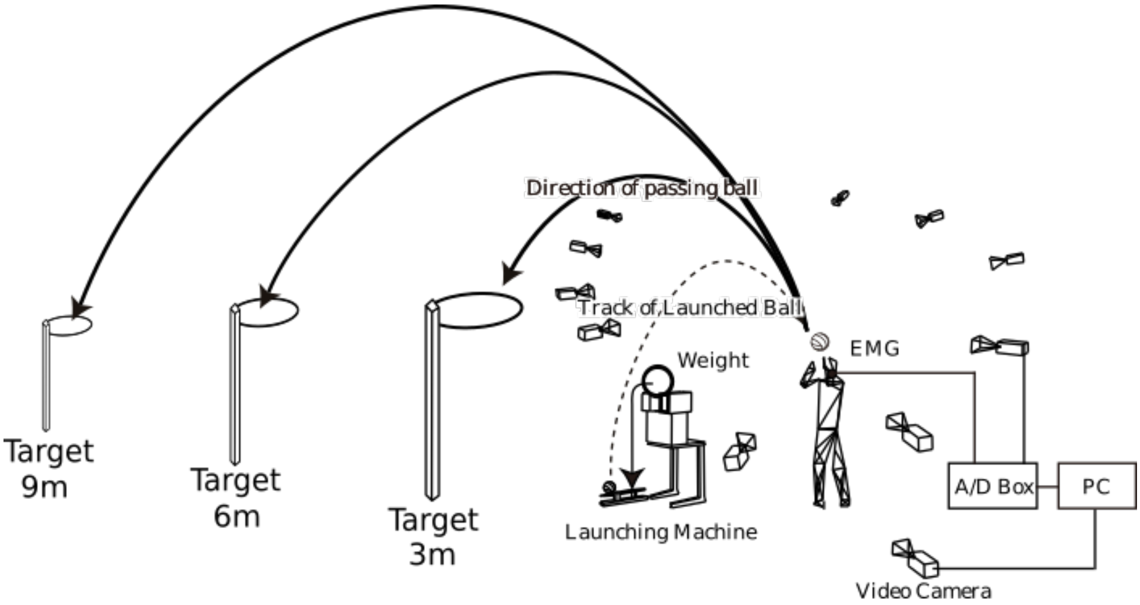


Figure 3-1 Outline of experiment

Above the subject are the capture cameras and the camera under the subject is the reference camera. The broken arrow is the track of the launched ball to the subject, and the solid arrows are the directions of the ball passed by the subject. The targets set at 3, 6 and 9m in front of a subject.

As an index of lower limb movement, the pelvis position was calculated. The average among three markers (right and left ASIS, PSIS) was obtained as the pelvis position. The elbow and wrist joint angles (θ) were obtained by the dot product. For the elbow joint, vector x was that from the elbow to the shoulder, and vector y was that from the elbow to the wrist. For the wrist joint, vector x was from the wrist to the elbow, and vector y was from the wrist to the hand. Where the wrist angle was greater than 180 degrees, the location was determined by observing the data. The angles were expressed mathematically as chapter 2-2. Angular velocities were calculated by differentiating the involved angles.

Electromyogram

We collected electromyographic (EMG) data from the a number of surface muscles on the right arm; Biceps Brachii (BB), Triceps Brachii (TB), Flexor Carpi Radialis (FCR), and Extensor Carpi Ulnalis (ECU). The recording from each area was accomplished with a wired bipolar electrode set (DL-141, S&ME Company, Japan) with a 12 mm separation. Sampling frequency for the EMG recordings was 2000Hz. Before attaching the electrodes, the skin was shaved and scrubbed to make a good electrical connection and to minimise the introduction of noise. Motion and EMG data were fed into a personal computer (Endeavor, EPSON Company, Japan) and could be synchronised using a known constant delay. At the end of each experimental session we recorded EMG of each muscle data for more than 3 sec isometric maximum voluntary contraction (MVC). The duration of the main phase was standardized as 100 % to compare motions for different target distances as Chapter 2 (Figure 2-2).

The calculation of Electromyogram

EMG data were passed through a Butterworth band-pass-filter with a 10-500 Hz bandwidth in order to remove high frequency random interference and motion artifacts of low frequency. The signal was then rectified. The EMG data for each muscle was standardised as %EMG using the value of the MVC. This can be expressed mathematically as described in Chapter 2-2. Then, I calculated the percent root mean square value (%RMS); this value has been related to constant force for a non-fatiguing contraction (Phinyomark et al., 2010) . %RMS is expressed as chapter 2-2.

The threshold of onset in EMG activity was determined by 3 times of standard deviation of back ground EMG from 1000 msec to 500 msec before ball touch.

Statistics

The actual calculations of joints angle, angular velocity and muscle activities were performed using MATLAB (Mathworks, USA). Data were statistically processed with IBM SPSS Statistics 25.0 (IBM Corporation, USA). Descriptive statistics were presented with average ± standard deviation and coefficient of variation. Repeated two-way measures ANOVA with Bonferroni correction was used to determine. The Pearson product-moment correlation coefficient was used for the relationship between two different indexes. The significant level was at $p < 0.05$.

3-3 Results

The ball projectile speeds increased with the target distances (3m: 5.5 ± 0.5 m/s, 6m: 8.1 ± 0.3 m/s, 9m: 10.3 ± 0.4 m/s). The projectile angle of the trial for distance of 3m was greater than that of 9m (3m: 59 ± 6 deg, 6m: 55 ± 3 deg, 9m: 53 ± 4 deg). The durations of main phase deferred significantly between 3m (136 ± 28 msec) and 9m (116 ± 21 msec, $p = 0.003$, $F(2,10) = 7.497$), and between 6m (126 ± 24 msec) and 9m ($p = 0.043$, $F(2,10) = 7.497$). The duration of the pull phase decreased as the target distances increased (3m: 68 ± 12 msec, 6m: 60 ± 11 msec, 9m: 54 ± 11 msec). The push phase durations were not significantly different among the three distances.

The averaged motion and muscle activities from 100 ms before ball touch to ball release are depicted in Figure3-2. The onsets of the elbow angular velocity increase (Figure3-2A) and TB activity (Figure3-2C) tend to became earlier as the target distance increased. However, for the onset of TB there was no significant difference among three different distances (3 – 6 m: $p = 0.206$, 6 – 9 m: $p = 0.629$, 3 – 9m: $p = 0.056$, $F(2,10) = 3.459$). As for the onset time of the FCR activity here were no significant differences among three different distances, but the onset time at the distance of 9m (-32 ± 2 msec) tend to be earlier than that of 3m (-15 ± 4 msec, $p = 0.075$, $F(2,10) = 4.715$).

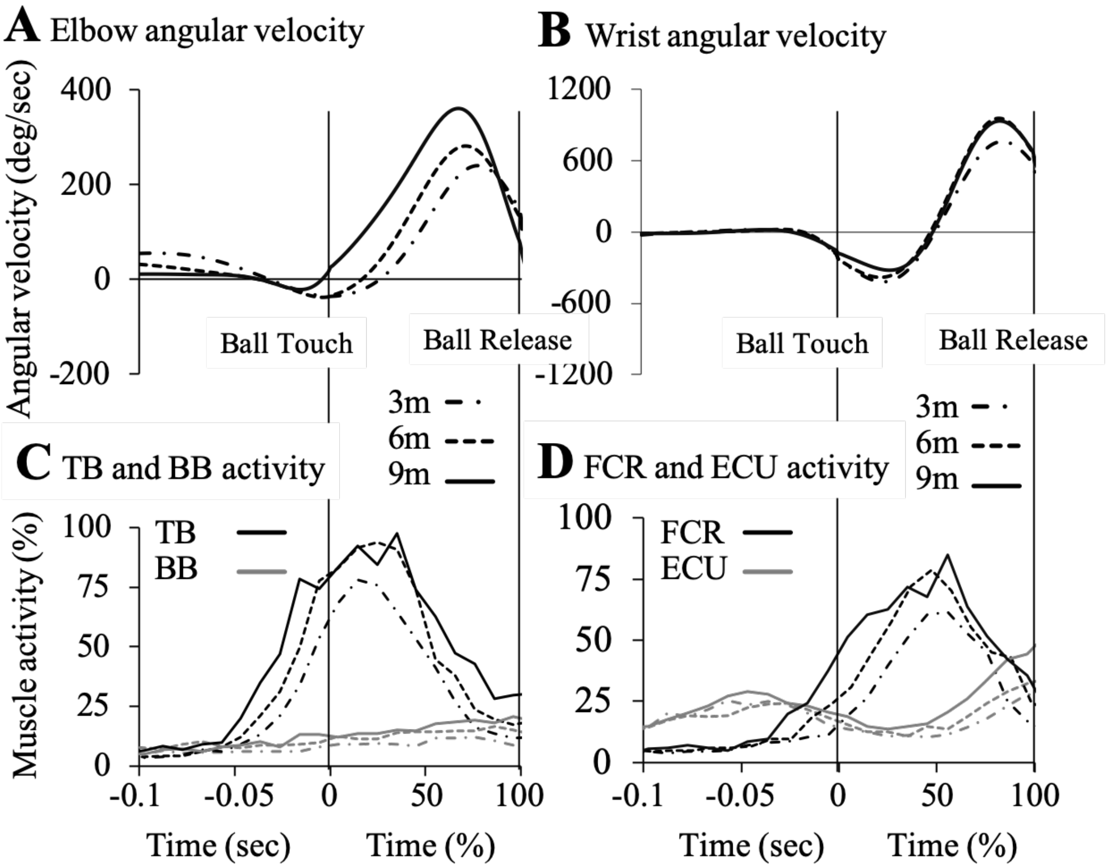


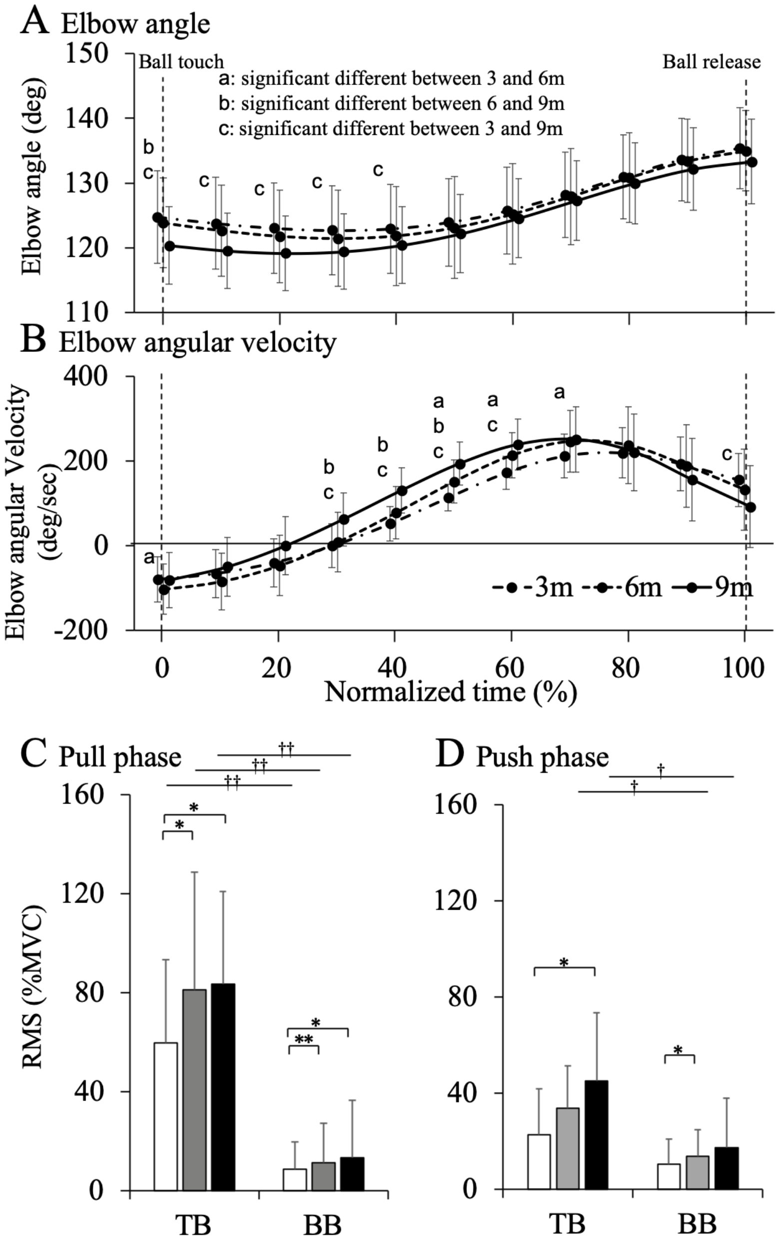
Figure3-2 The typical motion data and averaged muscle activities of all subjects

A and B show the averaged angular velocity of elbow (A) and wrist(B) from 0.1 sec before to end of main phase. Before ball touch the horizontal axis means real time, but from ball touch to ball release, the horizontal axis means normalized time because the duration time of main phase was different in each subjects. The vertical solid lines show the starting time of main phase. C and D show the averaged muscle activities of elbow (TB and BB, C) and wrist (FCR and ECU, D). The dashed-dotted, broken, and solid lines are 3m, 6m, and 9m trials respectively. In the EMG data, the black lines show the agonist (TB and FCR) and gray lines show the antagonist (BB and ECU) muscle activity.

Figure3-3 shows the averaged elbow motion and related muscle activities in the main phase. Elbow angles were significantly different between 3m and 9m trials in the period from 0 to 40 %, and in only 0 % there was significant difference between 6 and 9 m trials (Figure3-3A). Elbow angular velocities significantly differ between 3 and 9m trials in 30 to 60, and 100 % (Figure3-3B). From 30 to 50 %, there were significant differences between 6 and 9m, and from 50 and 70 % between 3 and 6m trials (Figure3-3B). The switching time from flexion to extension of elbow was significantly different between 3m (32 ± 7 %) and 9m (19 ± 13 %, $p = 0.013$, $F(2,10) = 3.459$) and between 6m (30 ± 4 %) and 9m ($p = 0.005$, $F(2,10) = 3.459$, Figure3-3C). In the pull phase the TB activity of the 3m (63 ± 42 %) was lower than that of 6m (84 ± 54 %, $p = 0.020$, $F(2,10) = 13.093$, Figure3-3C) and 9m (83 ± 37 %, $p = 0.021$, $F(2,10) = 13.093$, Figure3-3B). In push phase the TB activity of 3m (23 ± 19 %) was lower than that of 9m (45 ± 28 %, $p = 0.049$, $F(2,10) = 3.773$, Figure3-3D). There was no significant difference in the TB activities between 6m and 9m in either phase (pull phase, $p = 1.000$, $F(2,10) = 13.093$, push phase, $p = 0.092$, $F(2,10) = 3.773$, Figure3-3B and D). Figure3-5 shows the peak time of elbow and wrist angular velocity. The normalized times of peak times and related times with the ball release were plotted in the figure. The peak time of the elbow angular velocity (Figure3-5) became early with the target distances (3m: 78 ± 6 %, 6m:

72 ± 7 m/s, 9m: 68 ± 8 %, 3 – 6 m: $p = 0.002$, 6 – 9 m: $p = 0. 028$, 3 – 9m: $p = 0.002$, F (2,10) = 11.837).

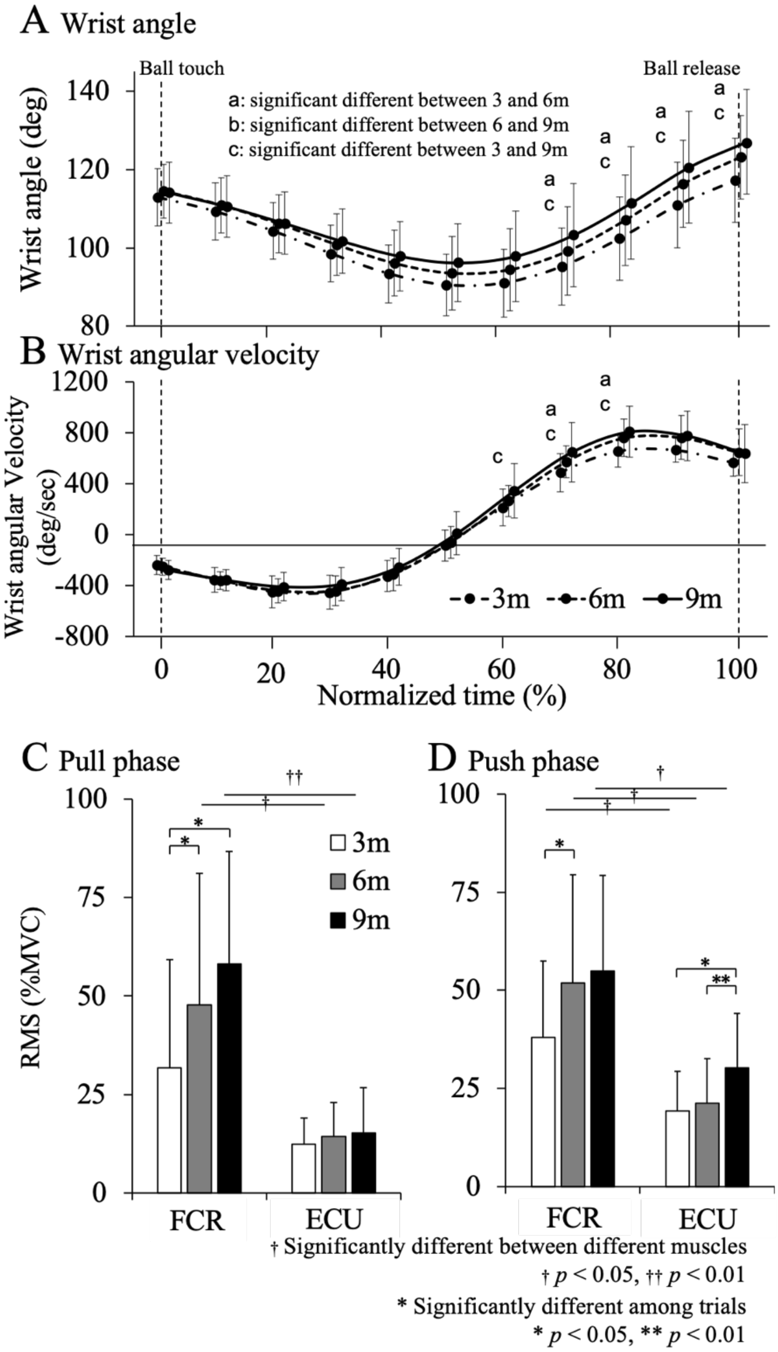
Figure3-4 shows the averaged motion and muscle activity of the wrist in the main phase. Wrist angles were significantly different between 3m and 6m and between 3m and 9m in the period from 70 to 100 % (Figure3-4A). In wrist angular velocity, there were significant differences between 3m and 6m in 70 and 80 %, and between 3m and 9m from 60 to 80% (Figure3-4B). In the pull phase the FCR activity in the 3m (32 ± 27 %) was lower than that in the 6m (48 ± 33 %, $p = 0.001$, F (2,10) = 20.575) or 9m (58 ± 28 %, $p = 0.001$, F (2,10) = 20.575, Figure3-4C). In the push phase the FCR activity of the 3m (38 ± 20 %) was lower than that of 6m (52 ± 28 %, $p = 0.012$ F (2,10) = 7.490) and 9m (55 ± 24 %, $p = 0.049$, F (2,10) = 7.490, Figure3-4D) in the pull phase. There was no significant difference in the FCR activities between 6m and 9m in both phase (pull phase $p = 0.250$, push phase $p = 1.000$, Figure3-4B and D). In pull phase the ECU activities were not significantly different among three different distances (Figure3-4C). In push phase, there were significant difference between 3m (19 ± 10 %) and 9m (30 ± 14 %, $p = 0.012$, F (2,10) = 6.957) and between 6m (21 ± 11 %) and 9m ($p = 0.009$, F (2,10) = 6.957, Figure3-4C). There was no significant deferent in peak time of wrist angular velocity among three deferent distances (3 – 6 m: $p = 1.000$, 6 – 9 m: $p = 0.597$, 3 – 9m: $p = 0.287$, $F(2,10) = 1.511$). When elbow and wrist peak times (real time) were calculated with the ball release set at 0 seconds, there was such no difference in the wrist peak time, but there is the tendency of that the elbow joint peak time was faster with the target distance increased (Figure3-5).



† Significantly different between different muscles
† $p < 0.05$, †† $p < 0.01$
* Significantly different among trials
* $p < 0.05$, ** $p < 0.01$

Figure3-3 Motion and EMG activity of elbow

A and B elbow angle and angular velocity, respectively against normalised time in the main phase. The dashed-dotted, broken, and solid lines are 3m, 6m, and 9m trials respectively. a: significantly different between 3m and 6m, b: significantly different between 6m and 9m, c: significantly different between 3m and 9m. C and D: activities of BB and TB in the pull phase (C), and in the push phase (D). White, gray, and black bars show 3m, 6m, and 9m respectively.



† Significantly different between different muscles

† $p < 0.05$, †† $p < 0.01$

* Significantly different among trials

* $p < 0.05$, ** $p < 0.01$

Figure3-4 Motion and EMG activity of wrist

A and B wrist angle and angular velocity, respectively against normalized time in the main phase. The dashed-dotted, broken, and solid lines are 3m, 6m, and 9m trials respectively. a: significantly different between 3m and 6m, b: significantly different between 6m and 9m, c: significantly different between 3m and 9m. C and D: activities of FCR and ECU in the pull phase (C), and in the push phase (D). White, gray, and black bars show 3m, 6m, and 9m respectively.

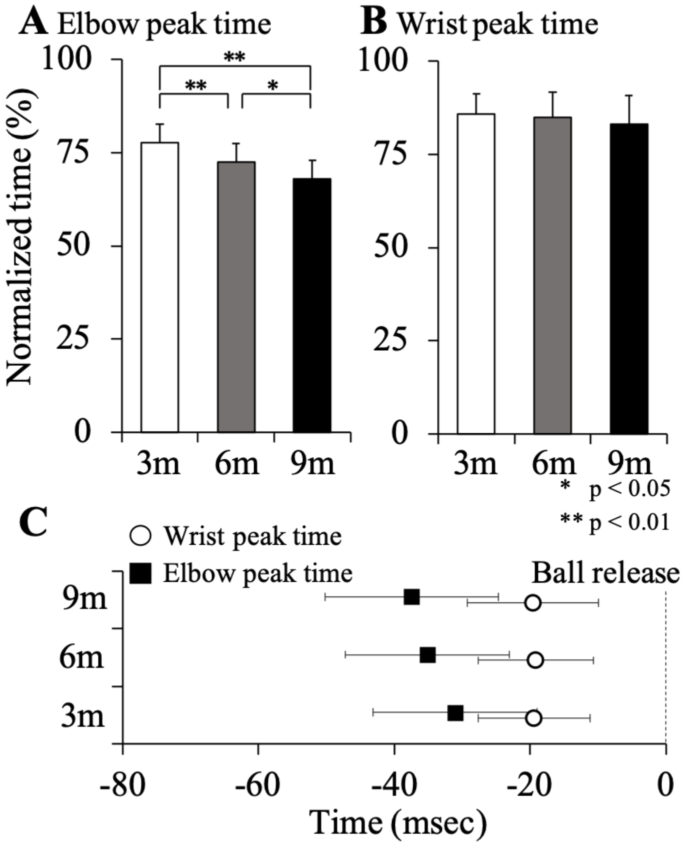


Figure3-5 The averaged peak time of joint angular velocity
A shows the peak times (normalized time) of elbow. B shows the peak times (normalized time) of wrist. A and B describe the data which white, gray, and black bars show 3m, 6m, and 9m respectively. White, gray, and black bars show 3m, 6m, and 9m respectively. C is the peak times (real time) of the elbow and wrist which were calculated with the ball release set at 0 seconds. The broken vertical line shows the moment of ball release.

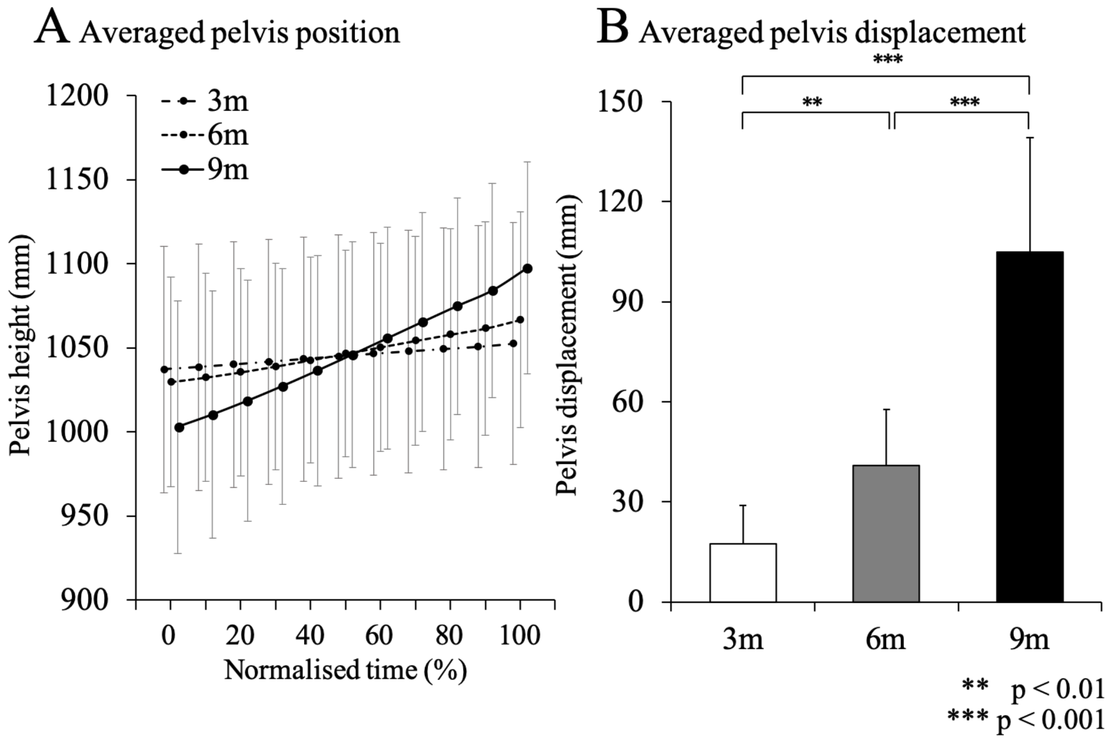


Figure3-6 The averaged pelvis height and displacement during main phase
A shows the averaged pelvis height changes during the main phase. The dashed-dotted, broken, and solid lines are 3m, 6m, and 9m trials respectively. B shows the averaged pelvis displacement during main phase. White, gray, and black bars show 3m, 6m, and 9m respectively.

The average of the pelvis displacement during main phase at distance of 3, 6, and 9m is shown in Figure3-6A. And Figure3-7 shows the typical successive pictures of overhead pass for short (3m) and long (9m) distances. There were significant differences in the pelvis displacements among three difference distances (Figure3-6B). The difference between 6m and 9m (64 ± 33 mm) was larger than that between 3m and 6m (24 ± 18 mm, $p < 0.001$, F (2,10) = 34.612).

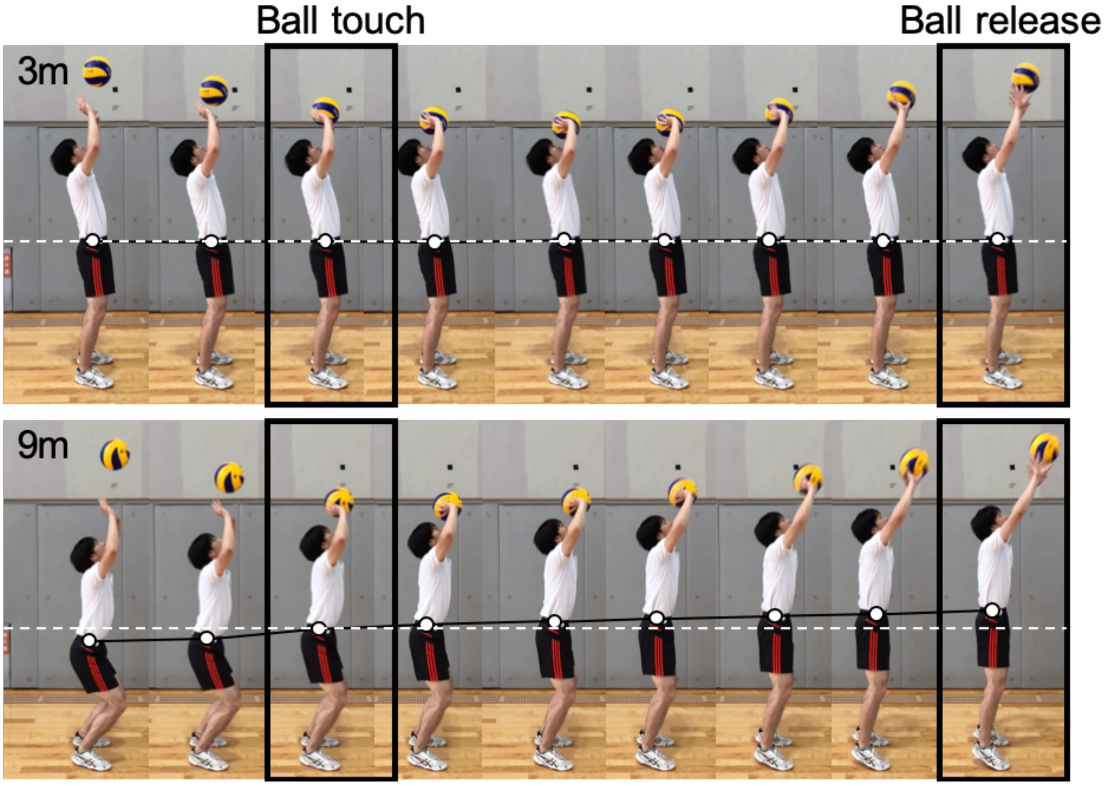


Figure3-7 Successive pictures of the short and long distance overhead pass
These are Successive pictures before ball touch to ball release. The white dots point the pelvis position. Upper pictures are short distance pass, lower pictures are long distance pass. The dashed white horizontal lines are the height of pelvis position at the ball touch.

The relationships between pelvis displacement and upper limbs are depicted in Figure3-8. When pooling the whole data of different distances, there was no significant relationship between pelvis displacement and upper limb movement. But when only the data of the 9m trials were taken into account, negative correlation was observed between pelvis displacement and elbow angular velocity (r = -0.491, p = 0.000). No such relation was obtained for the pooled data nor the data of any distances for the wrist.

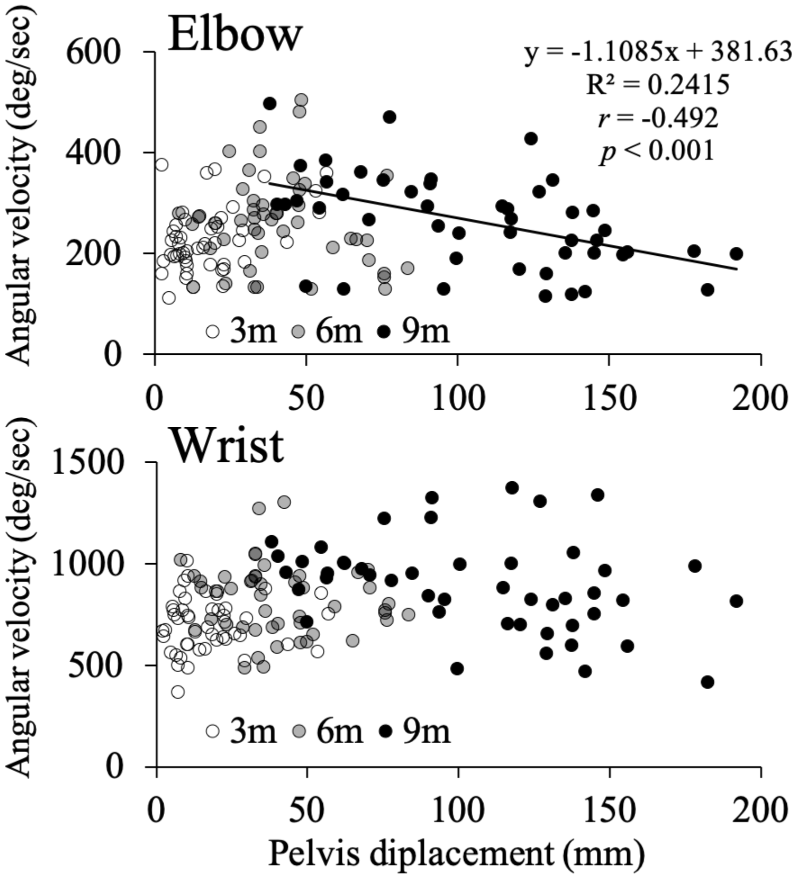


Figure3-8 The relationship between pelvis displacement and peak angular velocity. The upper graph shows the relationship between pelvis displacement and elbow angular velocity. The bottom graph shows the relationship between pelvis displacement and wrist angular velocity. The white, gray, and black dots are the 3m, 6m, and 9m, respectively. The regression line in the upper graph shows the regression line in the 9m trial. Significant correlation was only obtain between pelvis displacement and elbow angular velocity.

3-4 Discussion

There is only one biomechanical analysis of overhead pass in volleyball (Ozawa et al., 2019). However, that research analyzed only one distance of 6m. In the real games, the overhead pass has to be done at variety of distances with precise control. The main purpose of this chapter was to elucidate how the distances of overhead pass is controlled in elite volleyball players.

The utilization of the stretch-shortening cycle

There were significant differences in the duration of main phase. Especially the pull phase became shorter as the target distance increased. This was caused by that the elbow joint switched from flexion to extension earlier with the increase in target distances. But the onset time of TB was not significantly different among three distances. When the lower limb movement become greater, the inertia moment of forearm for flexion also become greater. The TB activity or onset time was decided by not only extension time but also the load with the body movement such as leg extension. So there was only a tendency that the onset time became earlier with the target distance increase (3 – 9m: $p = 0.056$).

There were significant differences in FCR activity during pull phase between 3 and 6m ($p = 0.001$) and between 3 and 9m ($p = 0.001$, Figure3-5C). The flexor muscle activity of the wrist in 6 and 9m trials were greater than that of extensor muscle. The wrist were extended in the pull phase at all distances (Figure3-4A and B). Thus the wrist flexor muscle was eccentrically contracted during the pull phase. This result follows the result of Chapter 2.

The lower limb functions

There were significant differences in the agonist muscle activities of the elbow and wrist during pull and push phase between 3 and 6m and between 3 and 9m (Figure3-3C, D, 3-5C, and D). However, there was no significantly difference in those between 6 and 9m. As for the TB activity, the 9m showed a lower value than the 6m. With regard to the joint angular velocities of the wrist, significant differences were found between 3m and 6m, but no significant difference was found between 6m and 9m. These results suggest that the other body parts would become more important for longer distance. Liu S. and Burton A. W (1999) reported that in basketball shot the leg function increased with the increase in goal distance (Liu & Burton, 1999). So in this chapter, the leg function was also investigated.

The difference in pelvis displacement between 6m and 9m was greater than that between 3m and 6m (Figure3-6, $p = 0.001$). This suggest that leg movement became more important in overhead passing for longer distance. Indeed, there are many studies that report the importance of lower and upper limb coordination in sport movement (Chiang & Liu, 2006; Hong, Cheung, & Roberts, 2001; Naito, Fukui, & Maruyama, 2012; Nakata & Araki, 2008). For example handball throwing velocity is strongly associated with lower limb strength (Ortega-Becerra, Pareja-Blanco, Jimenez-Reyes, Cuadrado-Penafiel, & Gonzalez-Badillo, 2018). The difference in pelvis displacement in overhead pass would support the insufficiency of the torque in upper arm.

The kinetic chain in the overhead pass

In this chapter, the angular velocity of elbow reached the peak earlier than the wrist that follows the result of Chapter 2. This indicates the proximal to distal pattern of kinetic chain from elbow to wrist. In the elbow, the difference of angular velocity was observed in the middle of the main phase (Figure3-4B). In the wrist, it was rather observed at the end of the main phase (Figure3-5B). In addition, although the peak time of the wrist was not changed among the three different distances, the peak of elbow angular velocity became earlier with the target distances. The hand is the final part to push the ball, so the peak time of the wrist could not be changed. The peak time of the elbow angular velocity, on the other hand, became earlier with the target distance increased because there would likely be an optimal time interval for energy from the elbow to the wrist for an efficient kinetic chain. Generally, for a skilled throw-like motion such as pitching (Seroyer et al., 2010), kicking (Chapman & Sanderson, 1990), and a push-like motion such as shot put (Čoh et al., 2008) the peak velocity appears, in the order, from the proximal to the distal joints.

Chapter 4

The overhead pass in the real game

4-1 Introduction

In Chapter 3, it was shown that the overhead pass of a short or middle distance was adjusted mainly with the upper limbs, and the pass of the long distance was adjusted with utilization of the lower limbs. However, the experiment was done in the laboratory, it is not in the real games, in which there are many situations of the performance of overhead pass. It is an open question whether the results of Chapter 3 are applicable to the action in real games. In this Chapter I obtain the characteristics of overhead pass in the real games.

4-2 Methods

Target Game

The target two games were in FIVB (French: Fédération International de Volleyball, English: International Volleyball Federation) Volleyball Nations League 2018, France versus Russia (Final game) and Poland versus USA (Final round Pool B). The world rankings of USA, Poland, Russia and France were 2, 4, 5 and 9, respectively. The results of the two games were shown in table 4-1. I analyzed all the 6 sets from video.

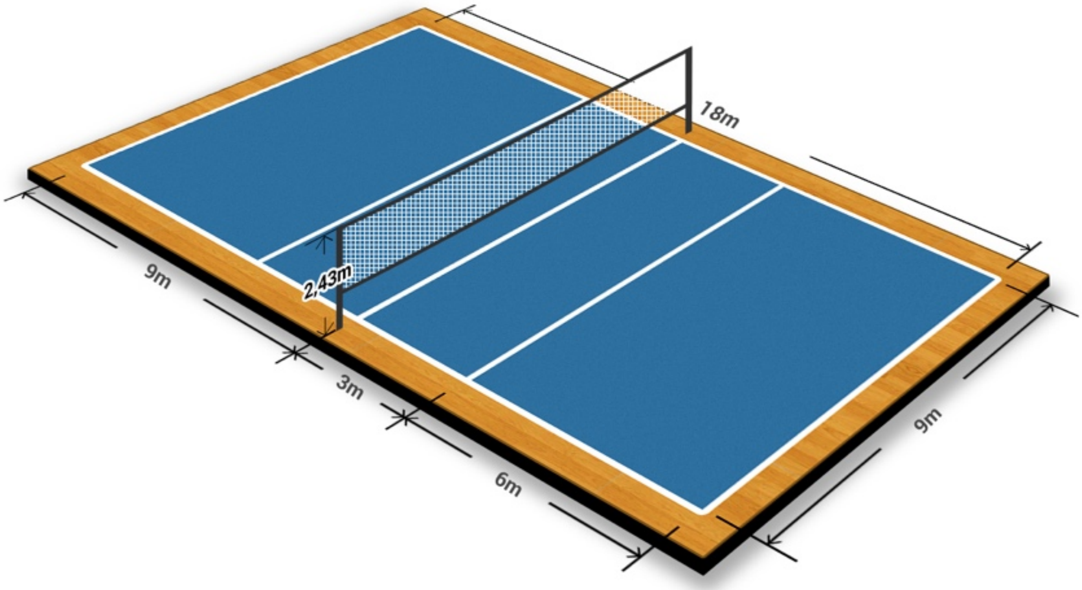
Table 4-1 The results of the target games
The top row describes the total set results, middle lines describe the results of each set.

	0-3	
France	22-25 20-25 23-25	Russia
Total	65 - 75	

	3-0	
USA	28-26 25-17 25-18	Poland
Total	78 - 61	

Classification of the performances

Setter's performance and non-setter's performances were analyzed separately. Overhead passes were classified into three according to the distances; short (~4m), middle (4 ~ 8m) and long (8m~). The judgement of the distance was made with reference to the coat lines (Figure 4-1). Subjective judgment was made by a volleyball specialist whether or not the lower body was utilized for those overhead passed done with standing on the floor. When they did overhead pass with lower limb movement, it was counted as "With leg". When they did overhead pass mainly utilize the upper limb movement, it was counted as "Without leg". When they did the overhead pass during jumping in the air, it was counted as "Jump".



https://mightygoods.com/volleyball-court/

Figure 4-1 The men’s volleyball coat

4-3 Results

The overhead pass performances of non-setters were 71 times in the two matches, and these of the setters were 227 times (Table 4-2). In the non-setters performance, the short, middle and long passes were 28, 29 and 14 times respectively (Table 4-2). In the setters performances the short, middle and long passes were 83, 105, 39 times respectively (Table 4-2).

Table 4-2 The times of the volleyball many kinds of the overhead pass

Distance	type of set	non-setter (times)	setter (times)
short	without leg	24	3
	with leg	1	0
	jump	3	80
middle	without leg	22	13
	with leg	4	1
	jump	3	91
long	without leg	2	8
	with leg	8	7
	jump	4	24
Total		71	227

In non-setters the ratio of the performances for short distance of Without leg, With leg and Jump were 86%, 4% and 11%, respectively (Figure 4-2). In non-setters the ratio of the performances for middle distance of Without leg, With leg and Jump were

76%, 14% and 10%, respectively (Figure 4-2). In non-setters the ratio of the performances for long distance of Without leg, With leg and Jump were 14%, 57% and 29%, respectively (Figure 4-2). On the other hand, the setters mostly did the overhead pass with jump, with the ratios of 96%, 87% and 62% for short, middle and long distances, respectively (Figure 4-2).

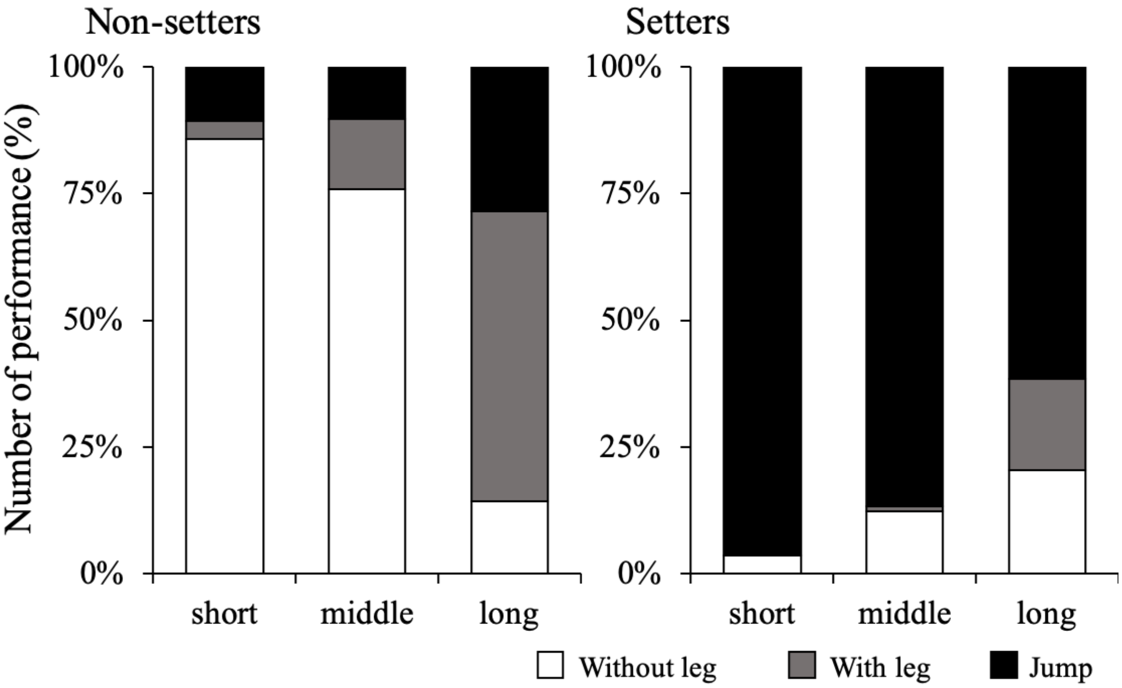


Figure 4-2 The number of the volleyball overhead pass
These graphs show the ratio of the overhead pass during the competitive game (Poland vs. Russia and USA vs. France of Volleyball Nations League). Left graph shows the non-setters performance, Right graph shows only setters performance.

In setters the ratio of the performances for short distance of Without leg, With leg and Jump were 4%, 0% and 96%, respectively (Figure 4-2). In setters the ratio of the performances for middle distance of Without leg, With leg and Jump were 12%, 1% and 87%, respectively (Figure 4-2). In setters the ratio of the performances for long distance of Without leg, With leg and Jump were 21%, 18% and 62%, respectively (Figure 4-2).

4-4 Discussion

In this chapter, the actual overhead pass in two real games of world competitive level, was analyzed because in Chapter 3 different movement of overhead movement was demonstrated depending on pass distances. Most of the overhead passes (227 times) were done by setters, 4 times more than those by non-setters (71 times, Table 4-2). Naturally, this is because setters have to set the ball to attackers. In the volleyball game, the attack is the most important play to get a point (Drikos et al., 2009; Eom & Schutz, 1992). In the two target games, the total points were 279 (table 4-1) and the point with the attack account for more than half (156 points). So most of the overhead passes were done by setters.

Non-setters performances

The results was lead the Chapter 3, when subjects pass a ball to the short or middle distance, they push the ball mainly with the upper limb (this is, without the leg). But at the long distance they actively used the legs. In the games analyzed, the total passes for long distance done by non-setters were only 14 times, not so many as compared with short or middle, but still the ratio of pass with leg was 57%, highest among the three pass distances. These results in the real games correspond well to the results of Chapter 3 obtained in the laboratory setting.

In overhead passes to the short and middle distances, the lower limb was utilized only rarely (short: 4%, middle: 14%, Figure 4-2). The situations in which non-setters do overhead pass would be mainly the pass to the setter (first touch). Because they are closed to the net for blocking before the first touch, they often pass the ball with stepping back. And after the overhead pass of the first touch they have to move to the position where they prepare for the next attack. In these overhead passes, they had to pass the ball highly, because they create time for attack preparation such as securing the distance for the approach. So these performances did not lead results in the Chapter 3. In the long distance passes, 14% overhead passes were not without leg. This suggest that the top level players are able to pass the ball for long distance from right side to left side of the coat even without utilizing the lower limb movement. But the situation makes them pass the ball without leg, because there was not enough time to move under the dropped ball.

Setters performances

The setters' performance is quite different from those of non-setter in that most of the pass was done with jump (jump setting). Even for long distances, 62% of the pass was with jumping. Recently, volleyball games are becoming faster, and faster settings are inevitably required (Hughes & Daniel, 2003). When setters set a ball to the attacker from high position, the attacking became quicker than that from low position. In the high-level games, success of the attack with a quick tempo is important to win (Palao, Santos, & Ureña, 2007). Thus, setters set a ball to the attacker as quickly and precisely as possible to avoid the block. If the time of passing a ball from a setter to an attacker became shorter, it would be difficult for the blockers on the opposite side to block the attack. Thus, setters would try to make the time short with jump setting. In fact, the most of setters' performances were "Jump" in this chapter. In a future, it would be interesting to analyze the motion of the jumping overhead pass.

Chapter 5

General discussion

The purpose of this thesis is 1) to find the key technical point of the overhead pass skill by comparing the motions in skilled and unskilled subjects, and 2) to obtain how the distances of overhead pass is controlled in elite volleyball players by comparing movements of passing a ball to different distances. I mainly analyzed the motion and muscle activities of overhead pass in the “main phase”, which was defined as the period from the ball touch to the ball release. This definition had not been done before. So from functional meaning the main phase were divided into pull and push phase.

In Chapter 2, I revealed the possibility of that ball propulsion by the skilled participants included the release of elastic energy from the wrist which was stored during the pull phase. Moreover, a kinetic chain - sequential development of joint angular velocity from the elbow to the wrist - was observed only in the skilled participants. Consequently, to develop an efficient, overhead pass, it would be important that the wrist flexors accumulate elastic energy during the pull phase. This energy can then be released in the push phase.

In Chapter 3, although the upper limb muscle activities were significantly different between 3m and 6m trials, no difference was observed between 6m and 9m. In addition, there is a negative correlation between pelvis displacement and elbow angular velocity only in 9m trials. In the distance of 3m and 6m, overhead pass distances would be mainly controlled by the upper body movements. For long distance of 9m the coordination of the upper and lower limb movements would be more important.

5-1 SSC in overhead pass

Many researches have been done on the SSC during motions that involve high power in the lower limbs (Carr et al., 2015; Harrison, Keane, & Coglan, 2004; Hassani et al., 2013; Masaki Ishikawa & Komi, 2004; Levenez et al., 2013; Norman & Komi, 1979; Serrien & Baeyens, 2017; Skurvydas et al., 2002; Suchomel et al., 2016). However, although there are several studies on SSC during low power motions(Fukunaga et al., 2001; M Ishikawa, Pakaslahti, & Komi, 2007; Lloyd, Oliver, Hughes, & Williams, 2012), the studies did not focus on the movement using the upper arms either (Yaghoubi et al., 2015). Thus the SSC during overhead pass is the first finding of SSC utilization in a quickly switching motion that involves low power in upper limb. Harrison et al. (2004) and Horita et al. (1996) suggested that the effects of SSC function increased with the increases in leg stiffness. In their study the leg stiffness was assessed from the torque data but the increases in the torque should accompany the increase in muscle activity. In addition, the muscle activity has strong correlation with muscle stiffness (Leonard et al., 2004). When the muscle stiffness increases, the tendon passively stored the elastic energy by disturbance. In Chapter 2, because the FCR activity in the skilled group in the present study was higher than that of the unskilled group, the skilled group should have greater wrist stiffness, and the SSC of the FCR would function more effectively than the unskilled group. The skilled group would be able to utilize the stored elastic energy more efficiently than was the unskilled group. In addition, during the knee extension with pre-flexion, the timing of starting up the quadriceps activity became earlier with the load increased (Earp, Newton, Cormie, & Blazevich, 2014). In Chapter 3, the start of the FCR and TB activity before ball touch also became earlier with the target distance increased (Figure3-2). Since the onset of muscle activity at an early timing enables ball touch in a high muscle activity, it might be possible to store more elastic energy of muscle tendon unit in the pull phase. Previous studies suggested the stiffness of tendon change with the training or any loading to tendon (Earp et al., 2014; Hirayama et al., 2017; Houghton, Dawson, & Rubenson, 2013; Kubo, Kawakami, & Fukunaga, 1999). This change in tendon stiffness is thought to be due to that the relationship between tendon length and stiffness is not linear, although the details are not disclosed. In overhead pass motion, the duration of the main phase decreased with the target distance increased, probably because the wrist tendon stiffness would increase with increase in the load to wrist.

Thus the utilization of SSC in the wrist is one of most important factors for passing a ball for all of distances. In elite volleyball player adjust the elastic energy which stored during pull phase depend on the distances of the passing the ball. In addition, the SSC of the wrist was not demonstrated in previous study. The present results would add the new knowledge of SSC or muscle tendon unit.

5-2 The kinetic chain during overhead pass

In chapter 2, the peak angular velocity for elbow joint in skilled group occurred earlier than that of writs joint, although the elbow joint angular velocity kept increasing in unskilled group. The sequence of peak times from proximal to distal joint produce efficiently energy flow for variable sports movements (Chapman & Sanderson, 1990; Serrien & Baeyens, 2017; Serrien et al., 2015; Yaghoubi et al., 2015). And torque reversal in proximal joint cause the counter torque increase in a linked distal segment (Herring & Chapman, 1992). The fact that such sequential movements from the proximal to distal joints was observed in skilled group in Chapter 2 (Figure 2-6A and 7A) suggested that the kinetic chain would be utilized in volleyball overhead pass, and inertia energy is transferred from the elbow to the wrist.

The benefit of the kinetic chain is not only transfer of inertia energy but also the SSC enhancement (Chapman & Sanderson, 1990; Grezios et al., 2006; N. T. Roach et al., 2013). In fast throwing motions, the passive interactive torques add to the net torque in the distal joints in the chain, whereas the proximal joint net torque is predominantly created by muscle torque (Serrien & Baeyens, 2017). This extension of the distal muscle and tendon by proximal reversal torque enhances the elastic energy in the distal muscle tendon unit (MTU). Thus from view point of kinetic chain, unskilled subjects did not efficiently coordinate elbow and wrist movements for utilization of energy at the wrist. In the chapter 3, the peak time (normalized time) of elbow angular velocity was significantly different among three different target distance. When elbow and wrist peak times (real time) were calculated with the ball release set as 0 sec, there was no difference in the wrist peak time, but the elbow joint peak time became earlier (Figure3-5). The difference between the wrist and the elbow angular velocity peak times was increased as the distance increased (Figure3-5B). The effects of SSC increase with the muscle stiffness, but there were not significant different in the FCR activity during the pull phase between 6 and 9m (Figure3-4 C). This result suggested that the elbow got the peak velocity at 9m earlier than that at 6m to transfer the greater energy to the wrist. For long distance overhead pass, the energy which flow from elbow to wrist increase because the energy created not only in the upper limb but also in the lower limb. This would be one factor of increasing lag of peak time between elbow and wrist. Then the MTU in the wrist would be more stretched in the 9m than 6m.

The pelvis displacement became greater with the target distance increase. Especially. the difference between 3m and 6m was greater than that between 6m and 9m (Figure3-6). In the upper limb, the agonist muscle activities (TB and FCR) were not significantly different between 6m and 9m (Figure3-3C and D, 3-5C and D). These results suggested that the lower limb movement would become more important for passing a ball to a long distance than that to the short or middle distances. Increasing the pelvis displacement means that the upper body moves upward more during the longer overhead pass. Since the load to the wrist of dropped ball become bigger with the lower limb movement, the load would make the MTU of the wrist extend. The stretching of MTU by the dropping ball load and upward body position shorten the push phase. By chaining these elements correctively during overhead pass in short time of 100 msec, the motion would become more smooth and pushing a ball become more efficiently.

5-3 Implications for coaching

In the real games of world competition level, 86% passes for short distance and

73% passes for middle distance were done by mainly upper limb in non-setter players (Figure 4-2). The results of Chapter 3 could be applied for the real games for the non-setters. And the 4% of short distance, 14% of middle distance and 14% of long distance overhead pass in the real games was not leaded the results. As explained in Chapter 4 there are the situation in which the short and middle distances pass which passes are necessary to create the time of preparation of attacks. And in some cases long distances passes lower limb was not utilized even for long distances passes, because they would be able to pass the ball for long distances mainly utilization of upper limb.

It is important for beginners of volleyball to practice short distances such as 3m and 6m in order to acquire overhand pass skills. Novice would be difficult to acquire the spring-like movement in the wrist. For the SSC utilization in the wrist, bounding overhead pass is effectiveness for beginner. The bounding pass is to repeat a vertical pass itself many times, the frequency would be better at 1.5 Hz. In the bounding pass training, the high intensity is not required for the arms, but it is efficient for feeling the extension of wrist using the soccer ball or basketball that are a few heavier than volleyball. They would do that the wrist movement and little elbow movement. One of the key points of this practice is that the elbow should not flex too much. And this practice is understood the sense of spring in the wrist and finger. After that, I inferred that the beginners can acquire how to move the elbows and wrists by making a pass the ball to a distance of 3m or 6m.

For the long distance such as 9m, lower limb movement would be needed. In the present thesis, I did not analyze the temporal indicator of lower limb movement such as knee joint angle or pelvis height velocity so the suitable timing of knee or ankle extension is not known. However, lower limb movement would contribute to ball flight distance for the long distance. Generally, the movement become difficult when the number of utilized joints increase. In the overhead pass for long distance, the coordination between not only elbow and wrist but also upper and lower limbs would be important. In the fact, there was correlation between pelvis displacement and the peak of elbow angular velocity (Figure3-8). So it would be better for beginners who learn the lower limb movement after they get the efficiently coordination between elbow and wrist movement.

Because recently the volleyball games are becoming faster, faster settings are required (Hughes & Daniel, 2003), the setter's high performance became more important to win in the world level. In the real game of world competitive level, 76% of all overhead passes were done by setters (Table 4-2). And the overhead pass by setters were almost jumping set (86%, Figure 4-2). The investigation of overhead pass skill with jumping also contribute to high level player. When they do the overhead pass during jumping, lower limb could not be utilized, so the upper limb should be utilized more efficiently than passing with standing. In addition, setters frequently pass the ball not only to the front but also to the back. These skills are also very important for overhead pass especially of the high level. It is an interesting topic to analyze these skills more in detailed that would be useful for coaching.

5-4 Limitations

In the present theses I analyzed only successful attempts. However, to clarify the characteristics of the control in detail, the accuracy of the movement should also be evaluated by including multiple trials including failed ones in future studies. In volleyball overhead pass the fingers should work to push and control a ball. In the present thesis, however, I analyzed only the movements of wrist and elbow joints in upper limb because finger movements are too complex and too small with many muscles involved. To draw conclusion on the role of SSC, future studies concerning the behavior of muscle tendon unit of fingers would also be necessary. And we could only suggest that the SSC was utilized in wrist movement during overhead pass from motion and EMG data without the behavior of muscle tendon unit itself.

5-5 Conclusion

I investigated the overhead motion and muscle activities of skilled and unskilled subjects, and the motion to pass the ball to variety of distances of elite volleyball players. As a result, following findings were obtained.

1) Ball propulsion by the skilled participants included elastic energy from the wrist which was stored during the pull phase (Chapter 2).
2) A kinetic chain was observed, sequential development of joint angular velocity from the elbow to the wrist, only in the skilled participants (Chapter 2 and 3).
3) In the short (3m) and middle (6m) distance, overhead pass distances would be mainly controlled by the upper body movements. For long distance of 9m the coordination of the upper and lower limb movements would be more important (Chapter 3).

References

Baker. (2007). The history of gait analysis before the advent of modern computers. *Gait Posture, 26*(3), 331-342. doi:10.1016/j.gaitpost.2006.10.014

Baker, D., & Nance, S. (1999). The Relation Between Running Speed and Measures of Strength and Power in Professional Rugby League Players. *The Journal of Strength & Conditioning Research, 13*(3), 230-235.

Bobbert, M. F., Mackay, M., Schinkelshoek, D., Huijing, P., & van Ingen Schenau, G. (1986). Biomechanical analysis of drop and countermovement jumps. *European Journal of Applied Physiology and Occupational Physiology, 54*(6), 566-573. doi:10.1007/BF00943342

Bosco, C., Ito, A., Komi, P., Luhtanen, P., Rahkila, P., Rusko, H., & Viitasalo, J. (1982). Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. *Acta Physiologica, 114*(4), 543-550.

Bosco, C., Komi, P. V., & Ito, A. (1981). Prestretch potentiation of human skeletal muscle during ballistic movement. *Acta Physiologica, 111*(2), 135-140.

Carr, C., McMahon, J. J., & Comfort, P. (2015). Relationships between jump and sprint performance in first-class county cricketers. *Journal of Trainology, 4*(1), 1-5.

Cavagna, Saibene, F., & Margaria, R. (1965). Effect of negative work on the amount of positive work performed by an isolated muscle. *Journal of Applied Physiology, 20*(1), 157-158.

Cavagna, G. A., Komarek, L., & Mazzoleni, S. (1971). The mechanics of sprint running. *The Journal of physiology, 217*(3), 709-721.

Chaouachi, A., Othman, A. B., Hammami, R., Drinkwater, E. J., & Behm, D. G. (2014). The combination of plyometric and balance training improves sprint and shuttle run performances more often than plyometric-only training with children. *The Journal of Strength & Conditioning Research, 28*(2), 401-412.

Chapman, A. E., & Sanderson, D. J. (1990). Muscular coordination in sporting skills. In *Multiple muscle systems* (pp. 608-620): Springer.

Chelly, M. S., Hermassi, S., Aouadi, R., & Shephard, R. J. (2014). Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. *The Journal of Strength & Conditioning Research, 28*(5), 1401-1410.

Chiang, H. Y., & Liu, Y.-T. (2006). *Coordination of basketball shooting movement of different skill level players.* Paper presented at the ISBS-Conference Proceedings Archive.

Čoh, M., Štuhec, S., & Supej, M. (2008). Comparative biomechanical analysis of the rotational shot put technique. *Collegium Antropologicum, 32*(1), 249-256.

Coleman, S. G., Benham, A. S., & Northcott, S. R. (1993). A three-dimensional cinematographical analysis of the volleyball spike. *J Sports Sci, 11*(4), 295-302. doi:10.1080/02640419308729999

Drikos, S., Kountouris, P., Laios, A., & Laios, Y. (2009). Correlates of team performance in volleyball. *International Journal of Performance Analysis in Sport, 9*(2), 149-156. doi:10.1080/24748668.2009.11868472

Earp, J. E., Newton, R. U., Cormie, P., & Blazevich, A. J. (2014). The influence of loading intensity on muscle–tendon unit behavior during maximal knee extensor stretch shortening cycle exercise. *European journal of applied physiology, 114*(1), 59-69.

Elftman, H. (1939). FORCES AND ENERGY CHANGES IN THE LEG DURING WALKING. *American Journal of Physiology-Legacy Content, 125*(2), 339-356. doi:10.1152/ajplegacy.1939.125.2.339

Elftman, H. (1940). THE WORK DONE BY MUSCLES IN RUNNING. *American Journal of Physiology-Legacy Content, 129*(3), 672-684. doi:10.1152/ajplegacy.1940.129.3.672

Eom, H. J., & Schutz, R. W. (1992). Statistical analyses of volleyball team performance. *Research quarterly for exercise and sport, 63*(1), 11-18.

Ficklin, T., Lund, R., & Schipper, M. (2014). A comparison of jump height, takeoff velocities, and blocking coverage in the swing and traditional volleyball blocking techniques. *Journal of sports science & medicine, 13*(1), 78.

Fukunaga, T., Kubo, K., Kawakami, Y., Fukashiro, S., Kanehisa, H., & Maganaris, C. N. (2001). In vivo behaviour of human muscle tendon during walking. *Proc Biol Sci, 268*(1464), 229-233. doi:10.1098/rspb.2000.1361

Grezios, A. K., Gissis, I. T., Sotiropoulos, A. A., Nikolaidis, D. V., & Souglis, A. G. (2006). Muscle-contraction properties in overarm throwing movements. *J Strength Cond Res, 20*(1), 117-123. doi:10.1519/r-15624.1

Hadzic, V., Sattler, T., Veselko, M., Markovic, G., & Dervisevic, E. (2014). Strength asymmetry of the shoulders in elite volleyball players. *Journal of athletic training, 49*(3), 338-344.

Harrison, A. J., Keane, S. P., & Coglan, J. (2004). Force-velocity relationship and stretch-shortening cycle function in sprint and endurance athletes. *The Journal of Strength & Conditioning Research, 18*(3), 473-479. doi:10.1519/13163.1

Hassani, A., Kotzamanidou, M. C., Fotiadou, E., Patikas, D., Evagelinou, C., & Sakadami, N. (2013). Neuromuscular differences between boys with and without intellectual disability during squat jump. *Research in developmental disabilities, 34*(9), 2856-

2863.

Herring, R. M., & Chapman, A. E. (1992). Effects of changes in segmental values and timing of both torque and torque reversal in simulated throws. *J Biomech, 25*(10), 1173-1184. doi:10.1016/0021-9290(92)90073-a

Hirayama, K., Iwanuma, S., Ikeda, N., Yoshikawa, A., Ema, R., & Kawakami, Y. (2017). Plyometric Training Favors Optimizing Muscle-Tendon Behavior during Depth Jumping. *Front Physiol, 8*, 16. doi:10.3389/fphys.2017.00016

Hong, D. A., Cheung, T. K., & Roberts, E. M. (2001). A three-dimensional, six-segment chain analysis of forceful overarm throwing. *J Electromyogr Kinesiol, 11*(2), 95-112. doi:10.1016/S1050-6411(00)00045-6

Houghton, L. A., Dawson, B. T., & Rubenson, J. (2013). Effects of plyometric training on achilles tendon properties and shuttle running during a simulated cricket batting innings. *J Strength Cond Res, 27*(4), 1036-1046. doi:10.1519/JSC.0b013e3182651e7a

Hughes, M., & Daniel, R. (2003). Playing patterns of elite and non-elite volleyball. *International Journal of Performance Analysis in Sport, 3*(1), 50-56. doi:doi.org/10.1080/24748668.2003.11868274

Ishikawa, M., & Komi, P. V. (2004). Effects of different dropping intensities on fascicle and tendinous tissue behavior during stretch-shortening cycle exercise. *Journal of Applied Physiology, 96*(3), 848-852.

Ishikawa, M., Komi, P. V., Finni, T., & Kuitunen, S. (2006). Contribution of the tendinous tissue to force enhancement during stretch–shortening cycle exercise depends on the prestretch and concentric phase intensities. *Journal of Electromyography and Kinesiology, 16*(5), 423-431.

Ishikawa, M., Pakaslahti, J., & Komi, P. (2007). Medial gastrocnemius muscle behavior during human running and walking. *Gait & posture, 25*(3), 380-384.

Janssen, I., Steele, J. R., Munro, B. J., & Brown, N. (2015). Previously identified patellar tendinopathy risk factors differ between elite and sub-elite volleyball players. *Scandinavian journal of medicine & science in sports, 25*(3), 308-314.

Kawakami, Y., Muraoka, T., Ito, S., Kanehisa, H., & Fukunaga, T. (2002). In vivo muscle fibre behaviour during counter-movement exercise in humans reveals a significant role for tendon elasticity. *The Journal of physiology, 540*(2), 635-646.

Kreighbaum, E., & Barthels, K. M. (1996). *Biomechanics: A Qualitative Approach for Studying Human Movement*: Allyn and Bacon.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *J Appl Physiol (1985), 87*(6), 2090-

2096. doi:10.1152/jappl.1999.87.6.2090

Leonard, C. T., Brown, J. S., Price, T. R., Queen, S. A., & Mikhailenok, E. L. (2004). Comparison of surface electromyography and myotonometric measurements during voluntary isometric contractions. *Journal of Electromyography and Kinesiology, 14*(6), 709-714.

Levenez, M., Theunissen, S., Bottero, A., Snoeck, T., Bruyère, A., Tinlot, A., . . . Provyn, S. (2013). The effect of a passive stretch training protocol on performance during a drop jump in humans. *The Journal of sports medicine and physical fitness, 53*(3), 319-326.

Liu, S., & Burton, A. W. (1999). Changes in basketball shooting patterns as a function of distance. *Percept Mot Skills, 89*(3 Pt 1), 831-845. doi:10.2466/pms.1999.89.3.831

Lloyd, R. S., Oliver, J. L., Hughes, M. G., & Williams, C. A. (2012). Age-related differences in the neural regulation of stretch–shortening cycle activities in male youths during maximal and sub-maximal hopping. *Journal of Electromyography and Kinesiology, 22*(1), 37-43.

Mary, E., Ridgway, & Jerry, W. (1987). A kinemamtic analysis of the front set and back set in volleyball. *Biomechanics in sport, III and IV*, 240-248.

Morse, C. I., Degens, H., Seynnes, O. R., Maganaris, C. N., & Jones, D. A. (2008). The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. *The Journal of physiology, 586*(1), 97-106.

Muybridge, E. (1878). The science of the horse's motions. *Sci Am, 39*, 241.

Naito, K., Fukui, Y., & Maruyama, T. (2012). Energy redistribution analysis of dynamic mechanisms of multi-body, multi-joint kinetic chain movement during soccer instep kicks. *Hum Mov Sci, 31*(1), 161-181. doi:10.1016/j.humov.2010.09.006

Nakata, R., & Araki, H. (2008). The Relationship of Muscular Peak Changes with Accuracy in an Over-arm Throwing Task. *Journal of Human Sciences, 16*, 9-16.

Nikos, B., Karolina, B., & Elissavet, N. M. (2009). Performance of male and female setters and attackers on Olympic-level volleyball teams. *International Journal of Performance Analysis in Sport, 9*(1), 141-148.

Norman, R. W., & Komi, P. V. (1979). Electromechanical delay in skeletal muscle under normal movement conditions. *Acta Physiologica, 106*(3), 241-248. doi:10.1111/j.1748-1716.1979.tb06394.x

Notarnicola, A., Fischetti, F., Gallone, D., Moretti, L., Pignataro, P., Tafuri, S., & Moretti, B. (2012). Overload and neovascularization of shoulder tendons in volleyball players. *BMC research notes, 5*(1), 397.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*(1), 97-113.

Ortega-Becerra, M., Pareja-Blanco, F., Jimenez-Reyes, P., Cuadrado-Penafiel, V., & Gonzalez-Badillo, J. J. (2018). Determinant Factors of Physical Performance and Specific Throwing in Handball Players of Different Ages. *J Strength Cond Res, 32*(6), 1778-1786. doi:10.1519/jsc.0000000000002050

Ozawa, Y., Uchiyama, S., Ogawara, K., Kanosue, K., & Yamada, H. (2019). Biomechanical analysis of volleyball overhead pass. *Sports Biomech*, 1-14. doi:10.1080/14763141.2019.1609072

Padulo, J., Tiloca, A., Powell, D., Granatelli, G., Bianco, A., & Paoli, A. (2013). EMG amplitude of the biceps femoris during jumping compared to landing movements. *Springerplus, 2*(1), 520.

Palao, J. M., Santos, J. A., & Ureña, A. (2007). Effect of the manner of spike execution on spike performance in volleyball. *International Journal of Performance Analysis in Sport, 7*(2), 126-138. doi:10.1080/24748668.2007.11868402

Pérez-Turpín, J. A., Zmijewski, P., Jiménez-Olmedo, J. M., Jové-Tossi, M. A., Martínez-Carbonell, A., Suárez-Llorca, C., & Andreu-Cabrera, E. (2014). Effects of whole body vibration on strength and jumping performance in volleyball and beach volleyball players. *Biol Sport, 31*(3), 239-245.

Phinyomark, A., Hirunviriya, S., Limsakul, C., & Phukpattaranont, P. (2010). *Evaluation of EMG feature extraction for hand movement recognition based on Euclidean distance and standard deviation.* Paper presented at the Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON), 2010 International Conference on.

Reeser, J. C., Fleisig, G. S., Bolt, B., & Ruan, M. (2010). Upper limb biomechanics during the volleyball serve and spike. *Sports health, 2*(5), 368-374. doi:10.1177/1941738110374624

Richards, D. P., Ajemian, S. V., Wiley, J. P., & Zernicke, R. F. (1996). Knee joint dynamics predict patellar tendinitis in elite volleyball players. *Am J Sports Med, 24*(5), 676-683. doi:10.1177/036354659602400520

Roach, N. T., Venkadesan, M., Rainbow, M. J., & Lieberman, D. E. (2013). Elastic energy storage in the shoulder and the evolution of high-speed throwing in Homo. *Nature, 498*(7455), 483.

Roach, N. T., Venkadesan, M., Rainbow, M. J., & Lieberman, D. E. (2013). Elastic energy storage in the shoulder and the evolution of high-speed throwing in Homo. *Nature, 498*(7455), 483-486. doi:10.1038/nature12267

Robertson, G. E., Caldwell, G. E., Hamill, J., Kamen, G., & Whittlesey, S. (2013).

Research methods in biomechanics: Human kinetics.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports health, 2*(2), 135-146.

Serrien, B., & Baeyens, J.-P. (2017). The proximal-to-distal sequence in upper-limb motions on multiple levels and time scales. *Human movement science, 55*, 156-171.

Serrien, B., Clijsen, R., Blondeel, J., Goossens, M., & Baeyens, J.-P. (2015). Differences in ball speed and three-dimensional kinematics between male and female handball players during a standing throw with run-up. *BMC Sports Science, Medicine and Rehabilitation, 7*(1), 27.

Skurvydas, A., Dudoniene, V., Kalvėnas, A., & Zuoza, A. (2002). Skeletal muscle fatigue in long-distance runners, sprinters and untrained men after repeated drop jumps performed at maximal intensity. *Scandinavian journal of medicine & science in sports, 12*(1), 34-39.

Suchomel, T. J., Sole, C. J., & Stone, M. H. (2016). Comparison of methods that assess lower-body stretch-shortening cycle utilization. *The Journal of Strength & Conditioning Research, 30*(2), 547-554.

Tilp, M., Wagner, H., & Muller, E. (2008). Differences in 3D kinematics between volleyball and beach volleyball spike movements. *Sports Biomech, 7*(3), 386-397. doi:10.1080/14763140802233231

van den Tillaar, R., Zondag, A., & Cabri, J. (2013). Comparing performance and kinematics of throwing with a circular and whip-like wind up by experienced handball players. *Scand J Med Sci Sports, 23*(6), e373-380. doi:10.1111/sms.12091

VencesBrito, A. M., Rodrigues Ferreira, M. A., Cortes, N., Fernandes, O., & Pezarat-Correia, P. (2011). Kinematic and electromyographic analyses of a karate punch. *J Electromyogr Kinesiol, 21*(6), 1023-1029. doi:10.1016/j.jelekin.2011.09.007

Wagner, H., Pfusterschmied, J., Tilp, M., Landlinger, J., Von Duvillard, S., & Müller, E. (2014). Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scandinavian journal of medicine & science in sports, 24*(2), 345-354. doi:10.1111/j.1600-0838.2012.01503.x

Yaghoubi, M., Esfehani, M. M., Hosseini, H. A., Alikhajeh, Y., & Shultz, S. P. (2015). Comparative Electromyography Analysis of the Upper Extremity Between Inexperienced and Elite Water Polo Players During an Overhead Shot. *Journal of Applied Biomechanics, 31*(2), 79-87.

Yiannis, L., & Panagiotis, K. (2005). Evolution in men's volleyball skills and tactics as evidenced in the Athens 2004 Olympic Games. *International Journal of Performance Analysis in Sport, 5*(2), 1-8. doi:10.1080/24748668.2005.11868322