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# 博　士　論　文

Joint Motion Analysis of the Upper Extremity

Required for Eating Activities

（食事動作における上肢の動作分析）

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# Joint Motion Analysis of the Upper Extremity Required for Eating Activities

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The purpose of this study was to determine differences in the range of upper extremity motion, the shoulder, elbow, forearm, and wrist joints, required for eating, between the utensils used, and three positions of the food vessel using an electromagnetic tracking instrument. The time required for the motion was also measured. Twelve subjects were studied as they performed eating tasks using either chopsticks or a spoon from a vessel placed at one of three distance positions. It was found that the ranges of motion required for eating with chopsticks were 19.5° to 56.8°, shoulder flexion, 10.3° to 25.6° shoulder abduction, 50.2° to 120.5° elbow flexion, -1.2° to 59.6° forearm supination, 13.3° to 28.8° wrist extension, and -3.8° to 11.3° wrist ulnar deviation. On the other hand, the ranges of motion required for eating with a spoon were 24.9° to 64.5° shoulder flexion, 14.4° to 29.2° shoulder abduction, 46.3° to 118.3° elbow flexion, -4.2° to 51.6° forearm supination, 18.1° to 29.0° wrist extension, and -0.4° to 17.1° wrist ulnar deviation. When chopsticks were used, the position of the vessel influenced the differences in shoulder flexion as well as the minimal elbow flexion. When a spoon was used, there were differences in shoulder flexion, maximal shoulder abduction, and minimal elbow flexion. Differences between chopsticks and spoons were observed in the maximum value of shoulder abduction when the vessel was placed at proximal, middle, and distal positions. Unfortunately, rotation of the shoulder could not be calculated; one reason being the difficulty in calculating the rotation angle of the upper arm within a series of body angles, because the position of 0° of rotation could not be well defined when the shoulder joint produced a combined motion of flexion and abduction (known as Codman's paradox).

Key words: Eating, Range of motion, Chopsticks, Spoon, 3D, Motion analysis

## Introduction

Eating, an important function of human daily life, involves three processes: motion of the upper extremity that takes food to the mouth, mastication, and swallowing. Posture control for maintaining a sitting position, is essential for upper extremity motion, and previous studies have determined the range of motion required for eating [1-7].

Safaee et al.[6] measured the range of upper extremity motion for eating with a spoon or a fork, and for drinking from a cup, and reported the following data: shoulder flexion: maximal 45°, minimal 5°, arc 40°; shoulder abduction, maximal 30°, minimal 5°, arc 25°; shoulder internal rotation, maximal 25°, minimal 5°, arc 20°; elbow flexion, maximal 130°, minimal 70°, arc 60°; forearm supination, maximal 60°, minimal -40°, arc 100°; wrist extension, maximal 20°, minimal 10°, arc 30°; and wrist ulnar deviation, maximal 20°, minimal -5°, arc 25°.

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However, they used a 3-D video measurement system and did not measure the motion for chopstick users. Tanaka et al.[7] used the same electromagnetic instrument to measure the range of upper extremity motion during eating with a spoon, fork or chopsticks, but they did not measure wrist motion. We have observed the range of motion for the shoulder, elbow, forearm, and wrist joints, using an electromagnetic tracking instrument that has advantages of better accuracy in measuring 3-D motion over conventional measurements such those by as video systems[8-11].

In the present study, we used an electromagnetic, 6-degree-of-freedom tracking instrument to measure simultaneously the motions of shoulder, elbow, forearm, and wrist joints in an eating motion. The aim of this study was to compare the range of upper extremity motion required for eating and the time required for the motion by changing the utensils used and the position of the food vessel.

## Subjects and Methods

1. Subjects

The subjects were 12 healthy students (average age 20.6 ± 1.2 years, range 19-24 years; 5 males and 7 females; average height 165.0 ± 6.9cm, range 151.0 - 172.0cm; upper arm length[from acromion to lateral epicondyle of humerus] 28.8 ± 1.8cm, forarm length[from lateral epicondyle of humerus to styloid process of radius] 24.6 ± 1.2cm). No subject had any past history of physiological or orthopedic disorders, and all were right-handed.

2. Measurement conditions

A chair with minimal metal components to eliminate magnetic effects and a wooden table 70cm high were used. The chair was adjusted so that the olecranon was at the same level as the top of the table (Figure 1). The food vessels were placed in the following three positions as with Kamakura's study[12] (Figure 2): (1) The proximal position was where the fingertip of the middle finger touched the food vessel in the neutral position of shoulder flexion/extension, abduction/adduction, internal rotation/external rotation, the elbow at 90° flexion, a neutral position of the wrist flexion/extension, and full finger extension. (2) The distal position was where the fingertip of the middle finger touched the food vessel with a 90° shoulder flexion, a neutral position of the shoulder internal rotation/external rotation, the elbow at full extension, a neutral position of the wrist flexion/extension, and full finger extension. (3) The middle position was

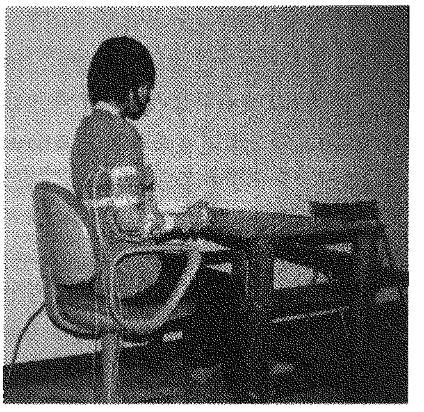

**Figure 1.** Position of subject.

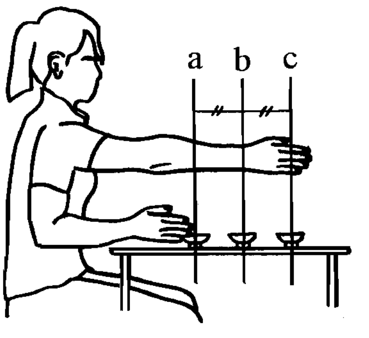


**Figure 2.** The positions of vessel.
a: proximal b: middle c: distal.
a-b and b-c are same distance.

halfway between the proximal and distal positions.

An electromagnetic tracking instrument system, (3 space, Polhemus Co, Ltd, USA) was used to measure the 3D motion of the shoulder, elbow, forearm, and wrist joints. To enable this, four sensors detecting angles were fixed to (1) part of the humerus, 10cm proximal from the olecranon, (2) the dorsal side of the proximal ulna, (3) the dorsal side of the distal end of the forearm, and (4) the dorsal side of the third metacarpal bone. The transmitter, from which the coordinates for the sensors originated, was mounted on a splint and fixed with a belt at the xiphoid processes of the sternum. To eliminate the effect of any magnetic fields, metal accessories and wrist watches were removed from the area between the transmitter and the sensors. Calculations were made on the basis of the angle information (Euler angle: azimus, elevation, and roll) of each sensor relative to the transmitter at 30 Hz. In the present study, the flexion angle of the shoulder joint was defined as the vector angle of the sensor at the distal part of the upper arm projected onto the sagittal plane. Similarly, the abduction angle was defined as the angle projected onto the coronal plane. To detect the flexion angle of the elbow joint, data was converted with coordinate transformation software (TRN3S, MP Japan, Tokyo, which converts data from the transmitter into a coordinate system relative to a given sensor) by using the sensor fixed at the distal end of the upper arm as the origin of a coordinate, i.e. the original data was converted into the data from the sensor fixed at the proximal part of the forearm relative to the new origin of coordinates. The flexion angle was defined as that obtained by projecting the vector of the sensor at the proximal part of the forearm onto the YZ plane. The forearm rotation angle was obtained from the difference in roll between the sensors placed at the proximal and distal parts of the forearm. The extension angle of the wrist joint was also converted with TRN3S so that the sensor at the distal end of the forearm became the origin of coordinates. The extension angle was defined as that obtained by projecting the vector of the sensor at the dorsum of the hand. The ulnar deviation angle was defined as the angle projected onto the XY plane. In this way, Euler angles were converted into the joint angles for a human body model. Finally, each joint angle was plotted against the time course during an eating motion.

3. Activities for measurement

"Eating pickles with a pair of chopsticks" and "Eating pickles with a spoon". A characteristic of pickles is that there is less possibility of dropping them compared with a more liquid food. The chopsticks were lacquered wood, 22.5cm long and weighing 10g. The spoon was a bamboo tablespoon, 20.0cm long and weighing 11.0g. The food vessel was a porcelain dish of 16.3cm diameter, 4 cm high and 3cm deep.

To prevent any supplementary movements during measurement, the trunk was fixed with a belt to the backrest of the chair. The third cycle of motion from the beginning of eating was measured in order to attain an eating motion close to normal motion. Data with less than 5 degrees of displacement between the angles of pre- and post-eating was subjected to further analysis. One motion in the present study defined as "from after picking up or spooning food from the vessel, taking the food to the mouth, to touching the food in the vessel again", i.e. "picking" or "spooning up" using a pair of chopsticks or a spoon was excluded. Taking food to the mouth was defined as "the first half", while back to the vessel was "the last half".

4. Items for analysis

The measured items were shoulder flexion and abduction, elbow flexion, forearm supination, and wrist extension and ulnar deviation, motion time (the first half, last half, and the total time). The following modification was introduced to the analysis of angles. The data was obtained at 30 Hz but the number of data points was different from person to person. To resolve this problem, the data points in the first and last half motions were assigned to frames 0 - 50 frames 50 - 100, respectively, i.e. there were 101 frames in total. The following method was used for the assignment. The measured angle data was proportionally allotted to calculate the data for 51 frames in the first half period so that the 50th frame corresponded to the time when the food was put into the mouth. For the last half, similarly, the data was treated so that the 100th frame corresponded to the time when the utensil contacted the food.

5. Statistical analysis

The Friedman test was used to compare the different positions of the vessel for each utensil, and if there were any significant differences, a multiple comparison Dunn test was made. The differences between chopsticks and spoons were analyzed using the Wilcoxon test. The level of significance was defined as less than 5%. Statistical

**Table 1.** The difference in ROM and time between the positions of the vessel. Using chopsticks.(ROM:degree,Motion:sec)

| | | chopsticks | | | difference | Pairwise comparison | | |
|---|---|---|---|---|---|---|---|---|
| | | proximal | middle | distal | between 3 positions | proximal VS middle | proximal VS distal | middle VS distal |
| shoulder flexion | max | 40.7± 9.7 | 44.7±10.2 | 56.8± 7.5 | *** | -4.0 | -16.1 ** | -12.1 * |
| | min | 19.5± 8.8 | 31.9± 8.4 | 42.5± 9.0 | *** | -12.4 * | -23.0 ** | -10.6 * |
| | arc | 21.1± 5.1 | 12.8± 3.6 | 14.2± 4.0 | ** | 8.3 ** | 6.9 ** | -1.4 |
| shoulder abduction | max | 18.6± 7.9 | 18.2± 8.5 | 25.6±11.9 | ** | 0.4 | -7.0 ** | -7.4 ** |
| | min | 12.8± 8.8 | 10.3± 8.6 | 10.3±11.6 | | 2.5 | 2.5 | 0.0 |
| | arc | 5.8± 2.5 | 7.9± 3.2 | 15.2± 7.4 | *** | -2.1 | -9.2 ** | -7.3 ** |
| elbow flexion | max | 119.7± 3.6 | 119.4± 3.8 | 120.5± 3.8 | * | 0.0 | -1.0 | -1.1 * |
| | min | 88.6± 6.6 | 69.9± 6.6 | 50.2± 5.9 | *** | 18.7 * | 38.4 ** | 19.7 * |
| | arc | 31.0± 6.5 | 49.5± 7.3 | 70.3± 8.2 | *** | -18.5 * | -39.3 ** | -20.8 * |
| forearm supination | max | 59.6± 9.8 | 55.8±13.0 | 53.5±15.1 | | 3.8 | 6.1 | 2.3 |
| | min | 0.0±14.2 | -0.9±10.8 | -1.2±12.9 | | 0.9 | 1.2 | 0.3 |
| | arc | 59.6±11.4 | 56.7± 8.7 | 54.7±11.9 | | 2.9 | 4.9 | 2.0 |
| wrist extension | max | 22.6± 6.9 | 26.1± 6.9 | 28.8± 6.7 | *** | -3.5 * | -6.2 ** | -2.7 |
| | min | 13.3± 8.1 | 14.3± 8.4 | 14.1± 5.8 | | -1.0 | -0.8 | 0.2 |
| | arc | 9.3± 3.3 | 11.8± 5.5 | 14.7± 5.0 | ** | -2.5 | -5.4 ** | -2.9 |
| wrist ulnar deviation | max | 11.3± 6.2 | 9.7± 6.3 | 9.6± 6.9 | | 1.6 | 1.7 | 0.1 |
| | min | 3.4± 5.9 | 1.0± 5.4 | -3.8± 7.0 | ** | 2.4 | 7.2 ** | 4.8 |
| | arc | 7.8± 4.3 | 8.7± 3.4 | 13.5± 6.1 | *** | -0.9 | -5.7 ** | -4.8 * |
| first half, sec | | 0.95±0.29 | 0.96±0.29 | 1.00±0.31 | | -0.01 | -0.05 | -0.04 |
| last half, sec | | 0.88±0.21 | 0.87±0.21 | 1.05±0.20 | * | 0.01 | -0.17 * | -0.18 * |
| total, sec | | 1.84±0.48 | 1.83±0.44 | 2.06±0.47 | * | 0.01 | -0.22 * | -0.23 |

(* : p<0.05, ** : p<0.01, *** : p<0.001) software STATview Ver.5 was used for the analyses. Differences of less than 10 degrees were not interpreted as large, even if it was statistically significant, and differences of 10 degrees or more were reviewed.

## Results

Table 1 shows the differences in joint angle among the various positions of the vessel when chopsticks were used. The ranges of average angles of shoulder flexion were 19.5 - 40.7 degrees for the proximal position, 31.9 - 44.7 degrees for the middle, and 42.5 - 56.8 degrees for the distal. The difference in maximal value was more than 10 degrees between the proximal and distal positions ($p<0.01$). Moreover, comparison between middle and distal revealed a difference of more than 10 degrees ($p<0.05$). Differences in minimal values were observed among the three positions. The proximal was smaller than the middle ($p<0.05$), and the middle was smaller than the distal ($p<0.05$). Similarly, the average angles of shoulder abduction were 12.8 - 18.6 degrees at the proximal vessel position, 10.3 - 18.2 degrees at the middle, and 10.3 - 25.6 at the distal. There were also differences in maximal value: 7.0 degrees between the proximal and distal ($p<0.01$) and 7.4 degrees between the middle and distal ($p<0.01$). However, these differences did not exceed 10 degrees. The average angles of elbow flexion were 88.6 - 119.7 degrees at the proximal vessel position, 69.9 - 119.4 degrees at the middle, 50.2 - 120.5 at the distal. There was a difference in maximal value between the middle and distal positions ($p<0.05$), however, this was a slight difference of 1.1 degrees. In contrast, there were marked differences of minimal values; 18.7 degrees between the proximal and middle position ($p<0.05$), 38.4 degrees between proximal and distal ($p<0.01$), and 19.7 degrees between middle and distal ($p<0.05$). The minimal values were in ascending order of proximal, middle, and distal positions. The average angles of forearm supination were 0.0 - 59.6 degrees at the proximal vessel placement, -0.9 - 55.8 degrees at the middle, and -1.2 - 53.5 degrees at the distal. There were no differences among the differing placements of the vessel. The average angles of wrist extension were 13.3 - 22.6 degrees at the proximal vessel placement, 14.3 - 26.1 degrees at the middle, and 14.1 - 28.8 degrees at the distal. There were differences in maximal values between proximal and middle ($p<0.05$) and proximal and distal ($P<0.01$). However, neither difference exceeded 10 degrees. The average angles of ulnar deviation of the wrist joint were 3.4 - 11.3 degrees at the proximal vessel placement, 1.0 - 9.7 degrees at the middle, -3.8 - 9.6 degrees at the distal. There was a difference in the minimal values between proximal and distal vessel placements ($p<0.01$). However, this difference did not exceed 10 degrees.

Table 1 also shows the average time required for the motions. The first half time to the mouth was 0.95 seconds for the proximal position, 0.96 seconds for middle, and 1.00 second for distal. The last half time from the mouth back to the food was 0.88 seconds for the proximal position, 0.87 seconds for middle, and 1.05 seconds for distal. The time required for one motion was 1.84 seconds for the proximal position, 1.83 for the middle, and 2.06 for the distal. There were differences among vessel positions in the last half between proximal and distal ($p<0.05$) and middle and distal ($p<0.05$). The distal position took longer in both cases.

Table 2 shows differences of joint angle depending on the placement of the

**Table 2.** The difference in ROM and time between the positions of the vessel. Using spoon. (ROM:degree,Motion:sec)

| | | spoon | | | difference | Pairwise comparison | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | between | proximal | proximal | middle |
| | | proximal | middle | distal | 3 positions | VS middle | VS distal | VS distal |
| shoulder | max | 53.8±11.4 | 59.1±10.7 | 64.5±10.8 | *** | -5.3 | -10.7 ** | -5.4 * |
| flexion | min | 24.9± 7.5 | 38.4± 7.0 | 48.3± 7.1 | *** | -13.5 * | -23.4 ** | -9.9 * |
| | arc | 28.9± 9.7 | 20.6± 8.2 | 16.2± 6.2 | *** | 8.3 ** | 12.7 ** | 4.4 |
| shoulder | max | 29.2±12.6 | 34.3±14.6 | 39.9±18.6 | * | -5.1 | -10.7 ** | -5.6 |
| abduction | min | 14.1± 5.7 | 12.1± 5.9 | 9.4± 8.8 | | 2.0 | 4.7 | 2.7 |
| | arc | 15.0± 8.5 | 22.1±12.3 | 30.5±16.2 | ** | -7.0 | -15.0 ** | -8.5 |
| elbow | max | 117.8± 4.2 | 117.9± 4.6 | 118.3± 4.7 | | 0.0 | -1.0 | -0.4 |
| flexion | min | 80.0± 7.1 | 65.6± 6.2 | 46.3± 7.9 | *** | 14.4 * | 33.7 ** | 19.3 * |
| | arc | 37.8± 8.2 | 52.2± 8.7 | 71.9±11.3 | *** | -14.4 * | -34.1 ** | -19.7 * |
| forearm | max | 51.5±11.3 | 51.6±13.7 | 51.0±14.2 | | -0.1 | 0.5 | 0.6 |
| supination | min | -4.2±10.7 | -1.1± 7.6 | 5.3±14.1 | | -2.9 | -9.5 | -6.4 |
| | arc | 55.7± 9.7 | 52.7±10.8 | 45.7± 9.9 | ** | 3.0 | 10.0 ** | 7.0 |
| wrist | max | 25.4± 7.1 | 28.3± 7.6 | 29.0± 6.0 | * | -2.9 | -3.6 * | -0.7 |
| extension | min | 18.1± 7.7 | 19.5± 5.9 | 20.2± 6.9 | | -1.4 | -2.1 | -0.7 |
| | arc | 7.3± 3.3 | 8.7± 3.7 | 8.8± 2.8 | | -1.4 | -1.5 | -0.1 |
| wrist | max | 16.4± 7.2 | 17.1± 8.1 | 16.6± 8.3 | | -0.7 | -0.2 | 0.5 |
| ulnar | min | 1.2± 9.9 | 2.4±10.6 | -0.4± 8.8 | | -1.2 | 1.6 | 2.8 |
| deviation | arc | 15.1± 8.7 | 14.6± 9.1 | 17.0± 8.1 | | 0.5 | -1.9 | -2.4 |
| first half, sec | | 1.01±0.26 | 1.03±0.23 | 1.12±0.28 | * | -0.02 | -0.11 * | -0.09 |
| last half,sec | | 0.93±0.24 | 0.90±0.25 | 0.95±0.28 | | 0.03 | -0.02 | -0.05 |
| total, sec | | 1.95±0.49 | 1.93±0.47 | 2.08±0.55 | | 0.02 | -0.13 | -0.15 |

(* : p<0.05, ** : p<0.01, *** : p<0.001)

vessel when a spoon was used. The average angles of shoulder flexion were 24.9 - 53.8 degrees for the vessel at the proximal position, 38.4 - 59.1 degrees for the middle, and 48.3 - 64.5 degrees for the distal. The difference in maximal value was more than 10 degrees between the proximal and distal positions ($p<0.01$) and there was also a difference, but less than 10 degrees, between the middle and distal positions ($p<0.01$). Differences in minimal values were observed among the three positions of the vessel. The values were in ascending order of the proximal, middle, and distal positions. Similarly, the average angles of shoulder abduction were 14.4 - 29.2 degrees at the proximal vessel placement, 12.1 - 34.3 degrees at the middle, and 9.4 - 39.9 degrees at the distal. There was a difference in maximal value (29.2 VS 39.9, $p<0.01$) of 10.7 degrees between the proximal and distal positions. The average angles of elbow flexion were 80.0 - 117.8 degrees for the proximal position, 65.6 - 117.9 degrees for the middle, and 46.3 - 118.3 degrees for the distal. There were marked differences in minimal values: 14.4 degrees between the proximal and middle position ($p<0.05$), 33.7 degrees between the proximal and distal ($p<0.01$), and 19.3 degrees between the middle and distal ($p<0.05$). The minimal values in ascending order were proximal, middle, and distal. The average angles of the forearm supination were -4.2 - 51.5 degrees at the proximal, -1.1 - 51.6 degrees at the middle and 5.3 - 51.0 degrees at the distal. There were no differences among the vessel positions. The average angles of wrist extension were 18.1 - 25.4 degrees at the proximal, 19.5 - 28.3 degrees at the middle and, 20.2 - 29.0 degrees at the distal. There were differences in maximal values between proximal and middle positions ($p<0.05$), however, the differences did not exceed 10 degrees. The average angles of ulnar deviation of the wrist joint were 1.2 - 16.4 degrees at the proximal vessel position, 2.4 - 17.1 degrees at the middle, -0.4 - 16.6 degrees at the distal, and -0.4 - 17.1 degrees altogether. There were no differences among vessel positions.

As for the average time required for the motion (Table 2), the first half time to the mouth was 1.01 seconds for the proximal position, 1.03 seconds for the middle, and 1.12 for the distal; the last half time from the mouth back to the food was 0.93 seconds for the proximal position, 0.90 seconds for the middle, and 0.95 seconds for the distal. The times required for an entire motion were 1.95 seconds for the proximal position, 1.93 seconds for the middle, and 2.08 seconds for the distal. There were differences among vessel positions in the first half time between the proximal and distal positions ($p<0.05$), the distal position taking longer.

Table 3 shows the comparison between the two implements for joint angles and vessel positions. When the vessel was at the proximal position, there were differences of more than 10 degrees in the maximal values of shoulder flexion and shoulder abduction; both values were larger using a spoon (flexion: $p<0.01$, abduction: $p<0.01$). There were also differences in the minimal value of shoulder flexion, maximal and

**Table 3.** Results from using two implements, and the difference between them. The bold character indicates a difference of 10 degrees or more. (ROM:degree,Motion:sec)

| | | proximal position | | | middle position | | | distal position | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | chopsticks | spoon | difference | chopsticks | spoon | difference | chopsticks | spoon | difference |
| shoulder flexion | max | **40.7± 9.7** | **53.8±11.4** | **-13.1** *** | **44.7±10.2** | **59.1±10.7** | **-14.4** *** | 56.8± 7.5 | 64.5±10.8 | -7.7 * |
| | min | 19.5± 8.8 | 24.9± 7.5 | -5.4 ** | 31.9± 8.4 | 38.4± 7.0 | -6.5 ** | 42.5± 9.0 | 48.3± 7.1 | -5.8 ** |
| | arc | 21.1± 5.1 | 28.9± 9.7 | -7.8 ** | 12.8± 3.6 | 20.6± 8.2 | -7.8 *** | 14.2± 4.0 | 16.2± 6.2 | -2.0 |
| shoulder abduction | max | **18.6± 7.9** | **29.2±12.6** | **-10.6** ** | **18.2± 8.5** | **34.3±14.6** | **-16.1** *** | **25.6±11.9** | **39.9±18.6** | **-14.3** ** |
| | min | 12.8± 8.8 | 14.1± 5.7 | -1.3 | 10.3± 8.6 | 12.1± 5.9 | -1.8 | 10.3±11.6 | 9.4± 8.8 | 0.9 |
| | arc | 5.8± 2.5 | 15.0± 8.5 | -9.2 *** | **7.9± 3.2** | **22.1±12.3** | **-14.2** ** | **15.2± 7.4** | **30.5±16.2** | **-15.3** *** |
| elbow flexion | max | 119.7± 3.6 | 117.8± 4.2 | 1.9 *** | 119.4± 3.8 | 117.9± 4.6 | 1.5 * | 120.5± 3.8 | 118.3± 4.7 | 2.2 ** |
| | min | 88.6± 6.6 | 80.0± 7.1 | 8.6 *** | 69.9± 6.6 | 65.6± 6.2 | 4.3 * | 50.2± 5.9 | 46.3± 7.9 | 3.9 |
| | arc | 31.0± 6.5 | 37.8± 8.2 | -6.8 ** | 49.5± 7.3 | 52.2± 8.7 | -2.7 | 70.3± 8.2 | 71.9±11.3 | -1.6 |
| forearm supination | max | 59.6± 9.8 | 51.5±11.3 | 8.1 ** | 55.8±13.0 | 51.6±13.7 | 4.2 * | 53.5±15.1 | 51.0±14.2 | 2.5 |
| | min | 0.0±14.2 | -4.2±10.7 | 4.2 | -0.9±10.8 | -1.1± 7.6 | 0.2 | -1.2±12.9 | 5.3±14.1 | -6.5 |
| | arc | 59.6±11.4 | 55.7± 9.7 | 3.9 | 56.7± 8.7 | 52.7±10.8 | 4.0 | 54.7±11.9 | 45.7± 9.9 | 9.0 * |
| wrist extension | max | 22.6± 6.9 | 25.4± 7.1 | -2.8 | 26.1± 6.9 | 28.3± 7.6 | -2.2 | 28.8± 6.7 | 29.0± 6.0 | -0.2 |
| | min | 13.3± 8.1 | 18.1± 7.7 | -4.8 | 14.3± 8.4 | 19.5± 5.9 | -5.2 | 14.1± 5.8 | 20.2± 6.9 | -6.1 * |
| | arc | 9.3± 3.3 | 7.3± 3.3 | 2.0 | 11.8± 5.5 | 8.7± 3.7 | 3.1 | 14.7± 5.0 | 8.8± 2.8 | 5.9 ** |
| wrist ulnar deviation | max | 11.3± 6.2 | 16.4± 7.2 | -5.1 ** | 9.7± 6.3 | 17.1± 8.1 | -7.4 * | 9.6± 6.9 | 16.6± 8.3 | -7.0 * |
| | min | 3.4± 5.9 | 1.2± 9.9 | 2.2 | 1.0± 5.4 | 2.4±10.6 | -1.4 | -3.8± 7.0 | -0.4± 8.8 | -3.4 |
| | arc | 7.8± 4.3 | 15.1± 8.7 | -7.3 ** | 8.7± 3.4 | 14.6± 9.1 | -5.9 * | 13.5± 6.1 | 17.0± 8.1 | -3.50 |
| first half, sec | | 0.95±0.29 | 1.01±0.26 | -0.06 | 0.96±0.29 | 1.03±0.23 | -0.07 | 1.00±0.31 | 1.12±0.28 | -0.12 |
| last half, sec | | 0.88±0.21 | 0.93±0.24 | -0.05 | 0.87±0.21 | 0.90±0.25 | -0.03 | 1.05±0.20 | 0.95±0.28 | 0.10 |
| total, sec | | 1.84±0.48 | 1.95±0.49 | -0.11 | 1.83±0.44 | 1.93±0.47 | -0.10 | 2.06±0.47 | 2.08±0.55 | -0.02 |

(* : $p<0.05$, ** : $p<0.01$, *** : $p<0.001$)

minimal values of elbow flexion, maximal value of forearm supination, and maximal value of wrist ulnar deviation but they did not exceed 10 degrees. Other measured items did not show any differences. When the vessel was at the middle position, there were also differences of more than 10 degrees in the maximal values of shoulder flexion and abduction; both values were greater when a spoon was used ($p<0.001$). Moreover, there were differences in the minimal value of shoulder flexion, maximal and minimal values of elbow flexion, maximal value of forearm supination, and maximal value of wrist ulnar deviation. However they did not exceed 10 degrees. When the vessel was at the distal position, there was a difference of more than 10 degrees in the maximal value of shoulder abduction, being greater with the spoon ($p<0.01$). There were differences in the maximal and minimal values of shoulder flexion, maximal value of elbow flexion, minimal value of wrist extension, and maximal value of wrist ulnar deviation. These did not exceed 10 degrees. However, the arc of forearm rotation showed a difference of about 10 degrees and it was greater with chopstick use ($p<0.05$). There were no differences in motion time among the three vessel positions.

The following observations can be made from the time series graphs in which the measured values of each subject were allotted to 101 frames and the allotted data of the subjects in each frame was averaged. In Figure 3-1, regardless of the tools or positions, the shoulder joint flexion shows a cone-shaped projection when the utensil was close to the mouth and the projection tended to be higher at either the beginning or the end of the motion; being higher the further away the vessel was from the utensil (Figure 3-1). For shoulder abduction (Figure 3-2), the graph shows a cone-shaped projection when

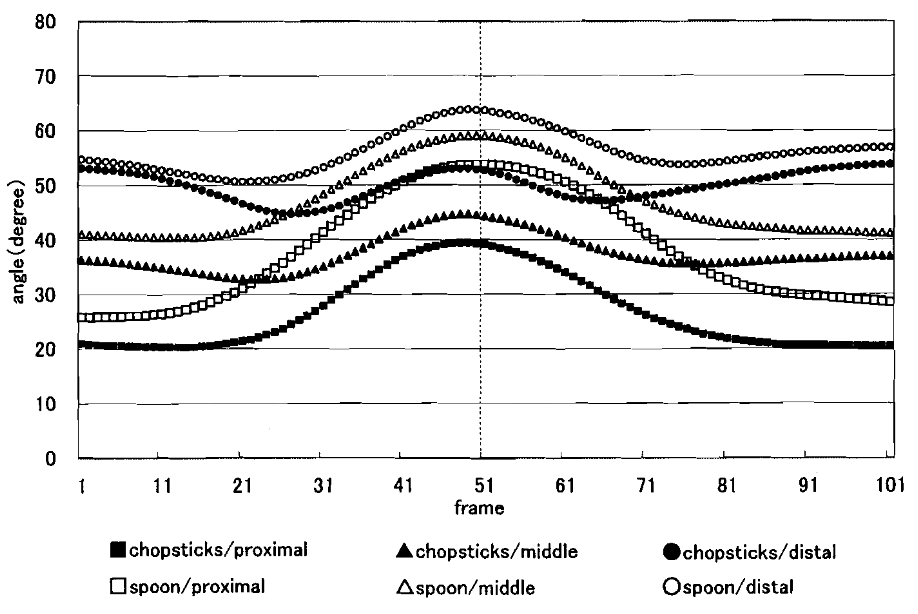


**Figure 3-1.** Time series graphs of shoulder joint flexion.

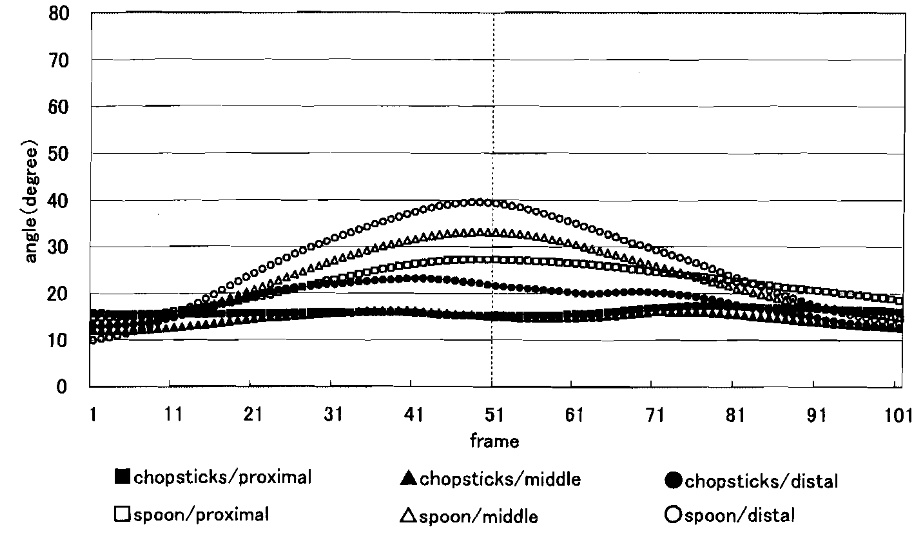


**Figure 3-2.** Time series graphs of shoulder joint abduction.

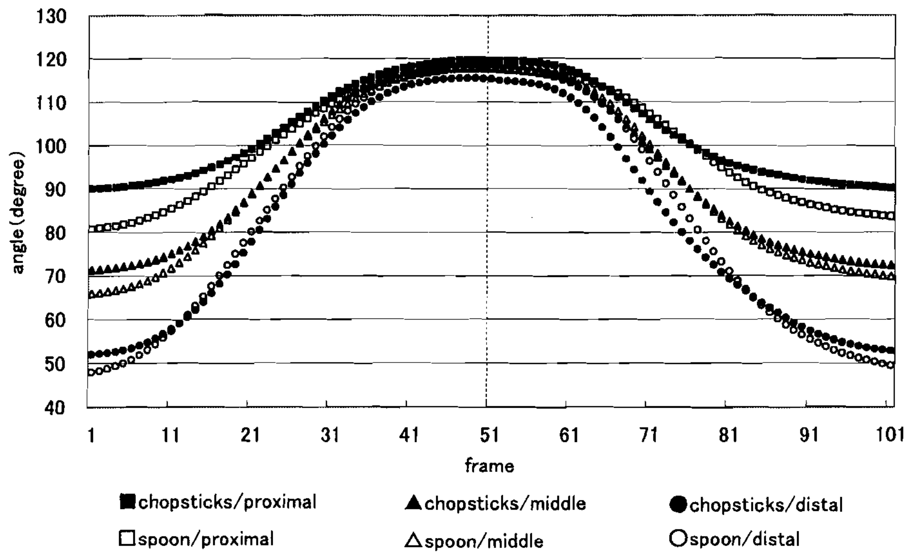


**Figure 3-3.** Time series graphs of elbow joint flexion.

a spoon was used, while the projection is not remarkable with chopsticks. The tendency observed in the elbow flexion is similar to that of the shoulder flexion. However, in contrast, the projection angle at the beginning and end tends to be lower with greater distance of the vessel from the utensil (Figure 3-3). The graph of forearm supination (Figure 3-4) shows a cone-shaped projection for both utensils when chopsticks were used;

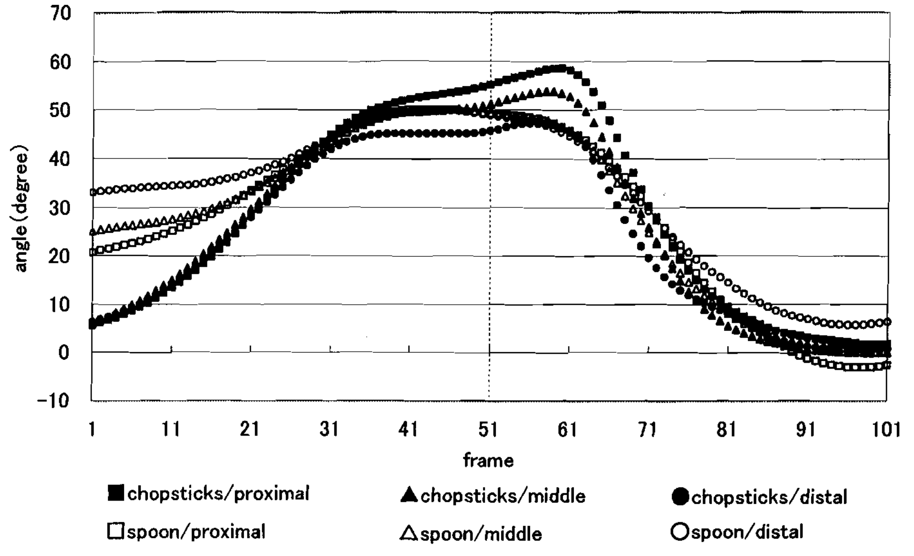


**Figure 3-4.** Time series graphs of forearm supination.

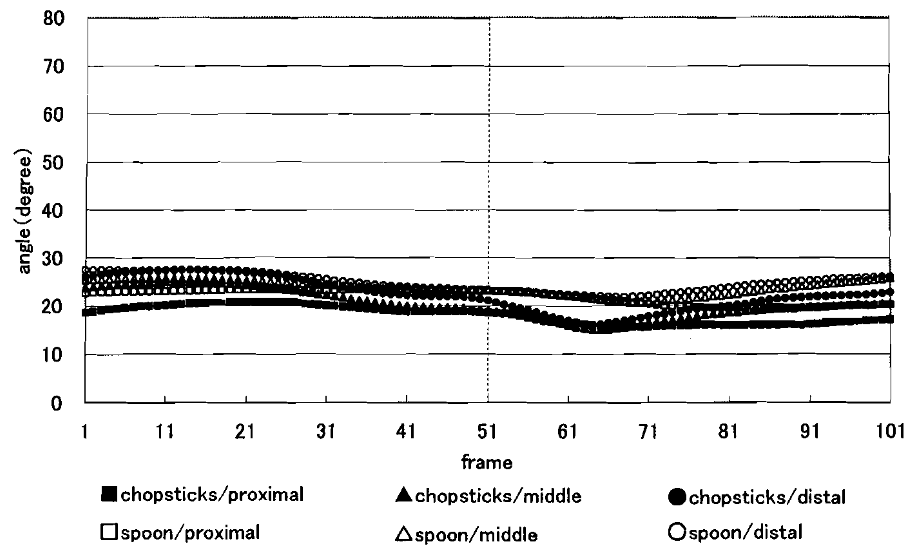


**Figure 3-5.** Time series graphs of wrist joint extension.

with the maximal angle tending to be observed immediately after removing the chopsticks from the mouth. In the extension of the wrist joint (Figure 3-5), the graph shows a valley-shaped depression and a minimal value appears after removing the chopsticks from the mouth. This means that a position of flexion of the highest degree appeared after pulling the chopsticks out from the mouth. When a spoon was used, the graph generally forms a valley-shaped depression. However, the extent of the depression is not

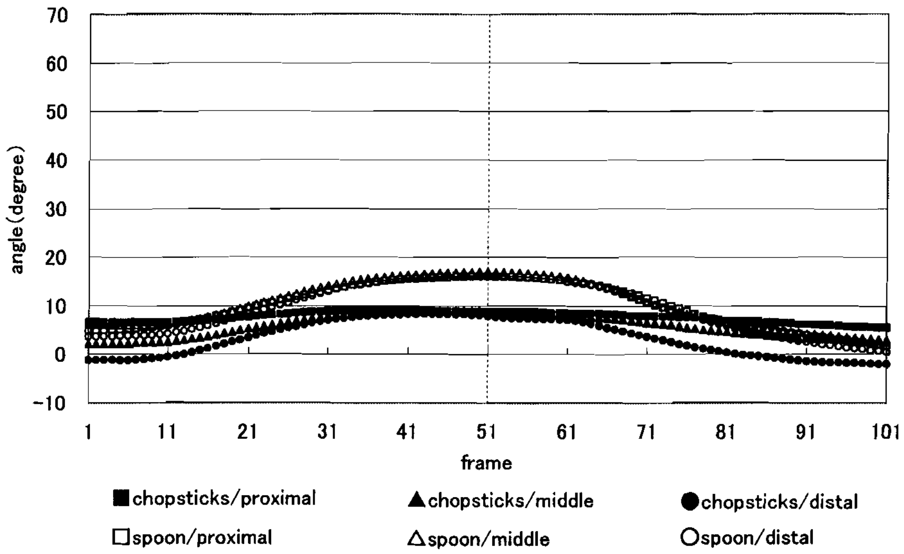


**Figure 3-6.** Time series graphs of wrist joint ulnar deviation.

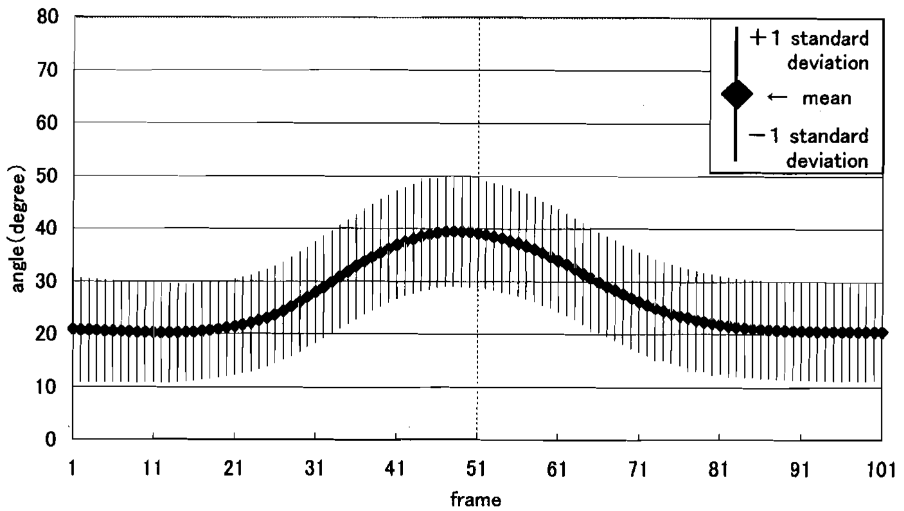


**Figure 4-1.** Shoulder joint flexion in using with chopsticks. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

as remarkable as with chopsticks. The ulnar deviation of the wrist joint (Figure 3-6) becomes a cone-shaped projection when a spoon was used, while with chopsticks and the vessel further away, the projection becomes flatter. The only case that shows minus values at the beginning and end of the motion is when chopsticks were used and the vessel position was distal.

Of the time series graphs of measured

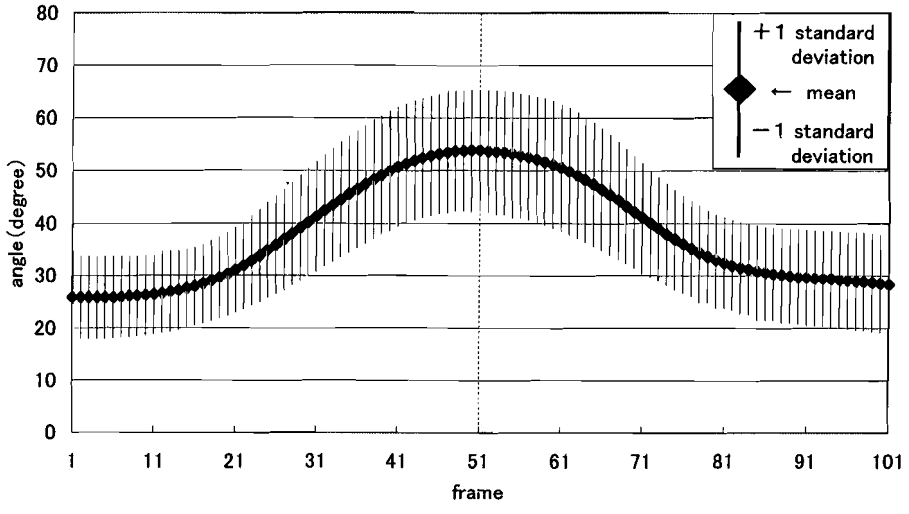


**Figure 4-2.** Shoulder joint flexion in using with spoon. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

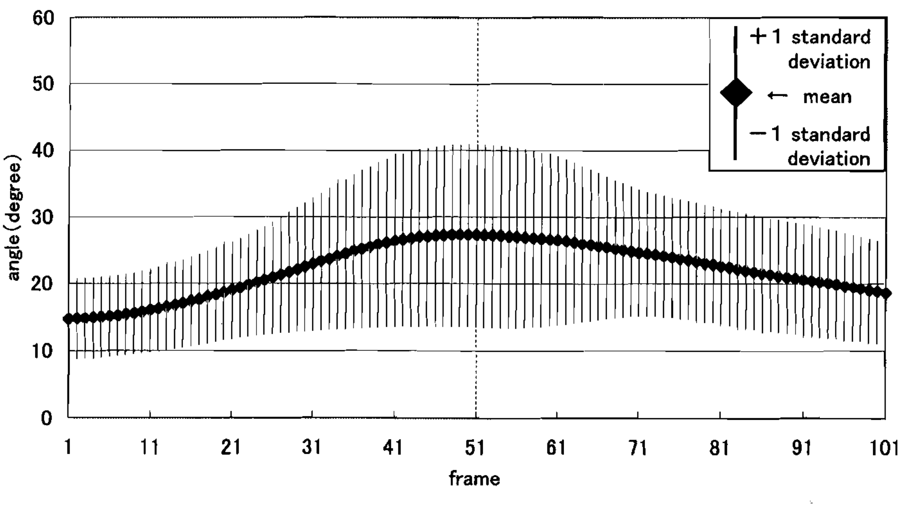


**Figure 4-3.** Shoulder joint abduction in using with spoon. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

values for all subjects, the standard deviation graphs demonstrated the following characteristics. The graphs of shoulder flexion angle show a cone-shaped projection with chopsticks as well as with a spoon, and the standard deviation shows a similar degree (Figure 4-1 and 2). However, in the shoulder joint abduction, the standard deviation becomes larger as the spoon is closer to the mouth, showing greater variance (Figure 4-

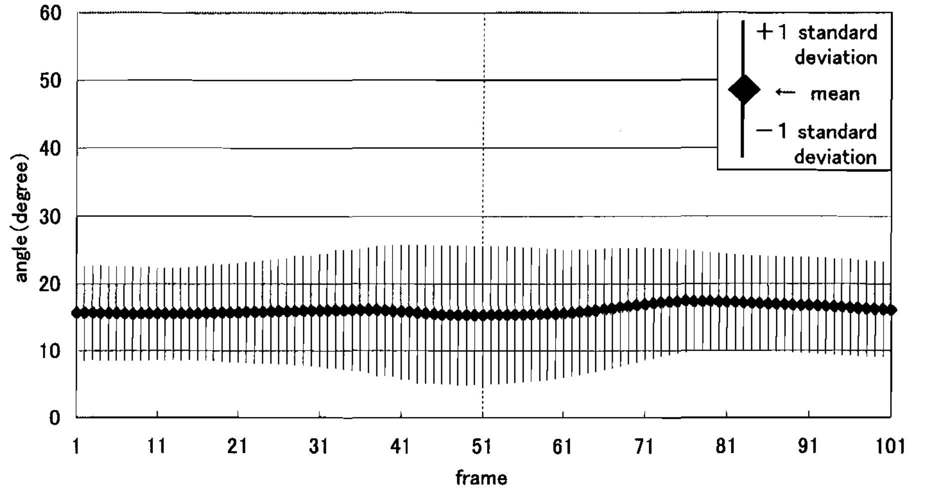


**Figure 4-4.** Shoulder joint abduction in using with chopsticks. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

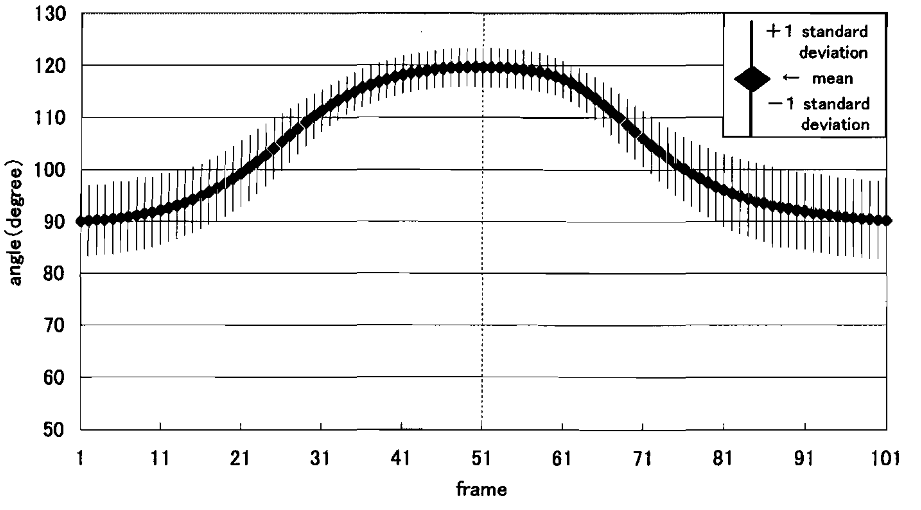


**Figure 4-5.** Elbow joint flexion in using with chopsticks. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

3). Chopsticks also have a similar tendency, but it is not as remarkable as with the spoon (Figure 4-4). The elbow joint flexion has a small standard deviation for both chopsticks and spoon users, indicating smaller variance among the subjects. In particular, the variance tends to be smaller when the utensil gets closer to the mouth (Figure 4-5 and 6).

## Discussion

1. Maximal and minimal values in the range of motion

The present study determined the

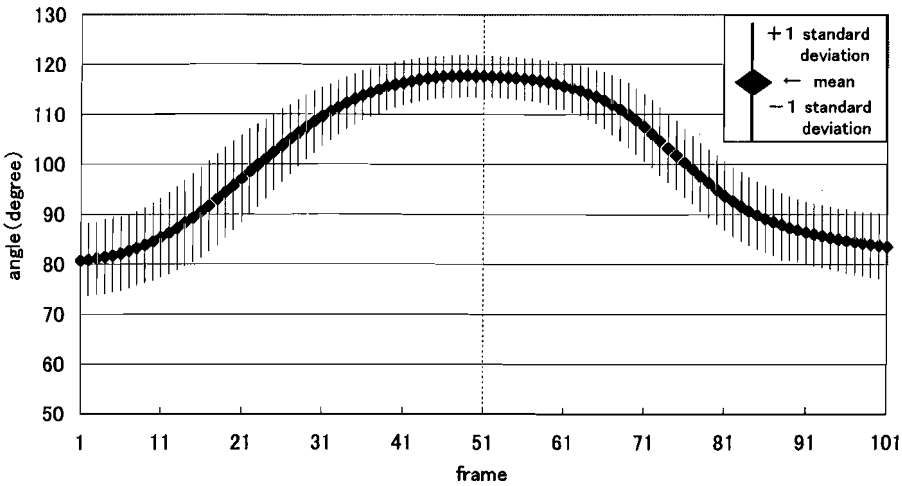


**Figure 4-6.** Elbow joint flexion in using with spoon. The vessel is proximal position. Time series graphs of mean angle and standard deviation at each frame in all subjects.

range of motion of the upper extremity required for eating with chopsticks or a spoon. In Safee et al.'s[6] study(Table 4), 10 subjects participated, and all were healthy, right-dominant men ranging in age from 20 to 29 years and in height from 167cm to 186cm. The subjects were seated on an adjusted chair until the forearm barely touched the table, and the range of motion of the upper extremity was then monitored when a spoon was used. Our results with a spoon had greater maximal and minimal values of shoulder flexion by 17.7 and 17.2 degrees, respectively, than those of the study by Safaee; but the arc of flexion of the shoulder joint was similar in both studies. The maximal and minimal values of the shoulder abduction were 7.4 and 7.5 degrees greater in our study, respectively, while the abduction arc was nearly the same value. The maximal and minimal values of the elbow joint flexion were 5.4 degrees and 21.2 degrees, respectively, lower in our study, while the elbow arc was 15.8 degrees greater. The forearm supination and pronation were 7.2 degrees and 18.7 degrees, respectively, lower in our study, and the difference of forearm arc was also as much as 25.9 degrees lower. These means that our subjects had the same shoulder motion as those in the study by Safaee et al. when eating with a spoon and both maximal and minimal values of the motion in our subjects were greater. Thus the Safaee et al. subjects were likely to have placed their elbow joint at a more posterior position than those in our study. In other words, with Safaee et al., the position of the food vessel was probably closer to the trunk than in our study. However, this is unclear because they did not describe its positioning. Moreover, their subjects probably used rotational movement of the forearm much more than elbow joint movement as compared with our subjects.

Tanaka et al.[7] have previously reported the shoulder, elbow, and forearm motion when a pair of chopsticks was used (Table 4). In that study, the four subjects were all healthy, right-dominant people ranging in age from 24 to 38 years. The subjects were

**Table 4.** Comparison with previous studies. (ROM:degree)

| author | | Safaee.RR et al. | | Tanaka et al. | | Nagao (proximal) | |
|---|---|---|---|---|---|---|---|
| Tools | | spoon | Total of cup, spoon, and fourk | chopsticks | spoon | chopsticks | spoon |
| first half motion | | - | - | - | - | 0.95 ±0.29 | 1.01 ±0.26 |
| last half motion | | - | - | - | - | 0.88 ±0.21 | 0.93 ±0.24 |
| total motion | | - | - | - | - | 1.84 ±0.48 | 1.95 ±0.49 |
| shoulder flexion | max | 36.1 ±13.7 | 45 | 29.5 ±10.6 | 44.3 ±14.7 | 40.7 ± 9.7 | 53.8 ±11.4 |
| | min | 7.8 ± 7.7 | 5 | 9.3 ±10.7 | 15.1 ± 5.2 | 19.5 ± 8.8 | 24.9 ± 7.5 |
| | arc | 28.3 ±10.0 | 40 | 20.2 | 29.2 | 21.1 ± 5.1 | 28.9 ± 9.7 |
| shoulder abduction | max | 21.8 ± 7.1 | 30 | 15.8 ± 5.5 | 33.2 ± 7.4 | 18.6 ± 7.9 | 29.2 ±12.6 |
| | min | 6.6 ± 9.9 | 5 | 6.0 ± 5.9 | 10.4 ± 5.4 | 12.8 ± 8.8 | 14.1 ± 5.7 |
| | arc | 15.2 ± 7.2 | 25 | 9.8 | 22.8 | 5.8 ± 2.5 | 15.0 ± 8.5 |
| shoulder internal rotation | max | 16.8 ±11.9 | 25 | - | - | - | - |
| | min | 4.8 ±12.0 | 5 | - | - | - | - |
| | arc | 12.0 ± 5.1 | 20 | - | - | - | - |
| elbow flexion | max | 123.2 ± 5.0 | 130 | 116.2 ± 6.9 | 116.4 ±10.4 | 119.7 ± 3.6 | 117.8 ± 4.2 |
| | min | 101.2 ± 8.1 | 70 | 82.1 ± 6.6 | 65.4 ± 4.9 | 88.6 ± 6.6 | 80.0 ± 7.1 |
| | arc | 22.0 ± 7.9 | 60 | 34.1 | 51.0 | 31.0 ± 6.5 | 37.8 ± 8.2 |
| forearm supination | max | 58.7 ± 5.8 | 60 | 49.9 ± 4.4 | 26.2 ± 6.6 | 59.6 ± 9.8 | 51.5 ±11.3 |
| | min | -22.9 ±14.6 | -40 | -18.2 ± 5.5 | -25.3 ± 6.9 | 0.0 ±14.2 | -4.2 ±10.7 |
| | arc | 81.6 ±17.5 | 100 | 68.1 | 51.5 | 59.6 ±11.4 | 55.7 ± 9.7 |
| wrist extension | max | 20.4 ± 8.7 | 20 | - | - | 22.6 ± 6.9 | 25.4 ± 7.1 |
| | min | 7.7 ± 9.0 | -10 | - | - | 13.3 ± 8.1 | 18.1 ± 7.7 |
| | arc | 12.8 ± 4.1 | 30 | - | - | 9.3 ± 3.3 | 7.3 ± 3.3 |
| wrist ulnar deviation | max | 4.2 ± 6.2 | 20 | - | - | 11.3 ± 6.2 | 16.4 ± 7.2 |
| | min | -4.4 ± 5.9 | -5 | - | - | 3.4 ± 5.9 | 1.2 ± 9.9 |
| | arc | 8.0 ± 2.4 | 25 | - | - | 7.8 ± 4.3 | 15.1 ± 8.7 |

seated on a 40cm high chair at a 63cm height table. The vessel was placed at a distance of about 30cm from subject's body. Compared with their study, the maximal and minimal shoulder flexions were 11.2 degrees and 10.2 degrees greater in our study, respectively, and the forearm pronation was 18.2 degrees smaller. These results suggest that the elbow joints of our subjects were always placed further anterior than those of the subjects of Tanaka et al.; and that their food vessel placement was lower than ours, so that their subjects needed greater pronation. However, the maximal supination was greater in our study. This means that their subjects took food to the mouth without much supination. This suggests the possibility that the trunk of their subjects was not fixed during measurement or they bent the neck more than our subjects did when taking food to the mouth. Moreover, when a spoon was used, the shoulder joint angle in their study showed a similar tendency to ours, while the minimal value of elbow flexion was smaller in their subjects, i.e. greater elbow extension and pronation, suggesting a lower vessel position in their study. Since the maximal value of supination in their study was smaller to that in our study, any supplementary trunk movement might have had a stronger influence, as in the case of eating with chopsticks, or the difference of maximal value of supination might be due to bending the neck. These results suggest that in measuring joint motion of the upper extremity in eating, the motion needs to control any supplementary trunk movement or neck flexion.

2. Comparison of vessel positions

When chopsticks were used, the position of the vessel influenced the differences in maximal and minimal shoulder flexion as well as minimal elbow flexion. There was also a slight difference in the last half time needed for the motion. The reason the minimal value of shoulder joint flexion became greater with a longer vessel distance was that the flexion angle at the start became large in order to reach the vessel at a greater distance. However, the maximal value of shoulder flexion was greater when the vessel was placed at the distal position rather than at proximal or middle positions. This may be due to the result of effective use of the upper extremity in the motion of eating. In other words, it might be a preparatory activity for the next reach by retaining the shoulder at a greater flexion angle whenever possible after reaching the vessel from a long distance and picking up the food. The minimal value of elbow flexion became smaller the further away the vessel was positioned. This may be caused by a wider extension of the elbow joint to reach the vessel, as was the case with the shoulder joint. In particular, the elbow arc of flexion increased from proximal, middle, to distal positions and these differences may be due to the disparity in angles to reach the vessel.

When a spoon was used, there were differences of maximal and minimal shoulder flexion, maximal shoulder abduction, and minimal elbow flexion among the positions of the vessels. The maximal value of shoulder flexion was larger when the vessel was placed at a distal rather than a proximal position. The maximal value of shoulder flexion appeared when the spoon was near the mouth. When the food was taken from the vessel at distal position, the shoulder joint already had a larger flexion at the beginning as compared with the vessel in the proximal position. This difference might be due to the effective use of the upper extremity in the motion of eating, as was the case with chopsticks. Similarly, the minimal value of elbow flexion became smaller as the vessel was positioned further away and this was probably caused by a wider extension of the elbow joint to reach the vessel. The maximal value of shoulder abduction that appeared was not observed in the motion with chopsticks. The maximal value of shoulder abduction was obtained as the spoon got closer to the mouth. This might be influenced by a motion to keep the shoulder abduction angle constant in order to eat the food after spooning it up.

3. Comparison between utensils

The difference in values between chopsticks and spoons was observed in the maximum value of shoulder abduction when the vessel was placed at proximal, middle, and distal positions. The abduction angle was greater for the spoon at any vessel position. The maximal value of shoulder abduction was observed when the spoon was close to the mouth, irrespective of the position of the vessel. When the abduction angle of the shoulder is small, ulnar deviation of the wrist is needed to take food to the mouth without dropping it. An ulnar deviation of 16.4 - 17.2 degrees had already been produced when the spoon was close to the mouth. Thus, when the shoulder was adducted, much ulnar deviation would be needed. To use the wrist joint efficiently without excess ulnar deviation when eating, the abduction angle of the shoulder must be widened much more when a spoon is used rather than chopsticks. This suggests that there is a lower possibility of dropping food with chopsticks, and thus there is no need to regulate motion by using the wrist joint and shoulder abduction. Another difference was observed in the maximal value of shoulder flexion when the vessel was positioned at the proximal and middle positions. These differences were greater maximal values of flexion in both positions when a spoon was used. This is similar to the shoulder abduction described above. It is suggested that the shoulder was abducted to reduce ulnar deviation of the wrist, and simultaneously the shoulder flexion angle became greater. To supplement this movement, the extension angle of the wrist increased at points on a graph that measured values of all subjects, and showed that the extension of the wrist joint tended to occur as the spoon got closer to the mouth.

4. Interpretation of graphs indicating standard deviations

The time series graphs of each measured item indicated that the standard deviation of shoulder abduction became greater as the spoon was closer to the mouth. Compared to eating with chopsticks, a spoon requires more care not to drop food. A comparison between utensils showed that this regulation to avoid dropping food was performed by a shoulder joint motion. Moreover, it is likely that this regulation differs greatly from person to person. By contrast the motion, including elbow flexion to regulate the distance to approach an object, tends to be relatively constant and can barely be influenced by individual differences because the spoon was placed closer to the mouth, the subjects tended to have experienced the motion repeatedly in daily life.

5. Motion time

The last half time with chopsticks was the same at the proximal and middle vessel positions and longer at the distal position. Since eating with chopsticks makes it necessary to pick up food, the degree of difficulty becomes greater with the distance of the vessel, and a longer time is needed to fit the tip of the chopsticks around the food. The longer time with the vessel at the distal position is thought to be due to the time required to grasp food. This was proven in that eating with a spoon, which did not need to grasp food, did not show any difference in the last half time at any position, while eating with chopsticks had differences. Eating with a spoon took longer in the first half time at the distal position than at the proximal position. With a spoon it is necessary to take food to the mouth without dropping it. It is suggested that the degree of difficulty becomes greater with the distance of the vessel and much more time was needed to take the food carefully. It was proven that eating with chopsticks, without the same propensity to drop food, took the same first half time in any position, while eating with a spoon showed differences in the first half time among vessel positions. The time required was no different between eating with chopsticks and with a spoon at any vessel position. This suggests that because eating is a highly-skilled motion, there was no difference among utensils but rather vessel positions, which influences the motion time.

6. Conclusion

Data detailing the ranges of motion and time for eating activities were obtained in this study. However, there are some cautions in generalizing from the results of this study. The data were obtained from healthy young Japanese people. A further study should be undertaken which includes other age groups and people of different races.

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