INTRODUCTION

Eating is a time-consuming activity of daily living and it is an activity that individuals with impairments want to improve. Social interactions and culture influence eating activity, which is important in rehabilitation as it deals with the issues of eating motion and position. In our experience of clinical interventions for the recovery of eating skills, effective intervention requires an understanding of the features of normal eating to facilitate evaluation of kinematic deviation from this norm. Recent studies have compared joint angles during eating in individuals with and without disabilities.

During rehabilitation, it is important to investigate and understand joint angles for kinematic evaluation during eating and to clarify the influences of gender and environmental factors.

Previous studies have assessed upper limb joint angles during normal eating. Upper limb joint angles change during the process of eating. When a spoon is brought from the dish toward the mouth, the shoulder joint flexion and abduction angles and the elbow joint flexion angle increase, whereas when chopsticks are brought from the dish toward the mouth, the shoulder joint flexion and elbow joint flexion angles increase. These angles decrease as the spoon or chop-
sticks are returned to the dish.\textsuperscript{14} Similarly, when a grasped cup is brought toward the mouth, the upper arm elevation and elbow joint flexion angles increase, while the upper arm rotation angle decreases. The wrist joint flexion angle increases and the forearm pronation angle decreases in the first half of this motion, whereas the wrist joint flexion angle decreases and the forearm pronation angle increases from the middle of this motion.\textsuperscript{15} In addition, studies have assessed variations in joint angles during eating according to the types of utensils or food items and differences in dish placement.\textsuperscript{14,16} Safaee-Rad et al.\textsuperscript{16} reported significant differences in shoulder joint flexion and abduction angles when subjects used a cup, fork, and spoon. Nagao\textsuperscript{14} reported significant differences in shoulder joint flexion and abduction angles, elbow joint flexion angle, forearm supination angle, and wrist joint extension and radial flexion angles when using chopsticks and when using a spoon. Moreover, changes in each upper limb joint angle were associated with variations in dish placement. Another study reported that a greater range of motion (RoM) in shoulder joint flexion and a lower RoM in elbow joint flexion are required when eating liquid foods than when eating solid foods.\textsuperscript{17} Previous reports, using various methods, have partially clarified the changes in upper limb joint angles during eating and their variation according to the types of utensils and food items as environmental factors. Eating involves different subtasks, such as biting and drinking using a cup.\textsuperscript{18} Eating with a spoon or chopsticks involves basic motions of the upper extremities, including reaching to the dish or mouth, scooping or picking up food, and taking food into the mouth.

Previous research on realistic eating using a fork found that the range of normal head forward inclination angles, but not joint angles from the starting position to the maximal mouth opening position, were significantly greater in men than in women.\textsuperscript{19} Therefore, gender differences in joint angles during eating may exist. Joint angles during eating have been reported for men and for women\textsuperscript{10,16,20–22}, however, no study has investigated gender differences. Therefore, the present study aimed to examine the upper limb joint angles separately in young, healthy Japanese men and women and to investigate gender differences during eating with a spoon and with chopsticks.

\section*{MATERIALS AND METHODS}

\subsection*{Participants}

The participants in the present study were healthy Japanese volunteers aged 20–39 years. All were right-handed and were recruited from among our institutional staff. Subjects comprised 12 men (mean age, 28.8 ± 4.9 years; height, 172.0 ± 6.1 cm) and 13 women (mean age, 26.3 ± 4.3 years; height, 161.2 ± 4.6 cm). Participants were sufficiently experienced in using a spoon and chopsticks during eating. This was confirmed based on demonstration of a comfortable motion of eating and on an oral question-and-answer session. None of the participants had any neurological diseases. Prior to participation, subjects received an explanation of the study and provided written consent. The present study was approved by the Research Ethics Committee of the University of Miyazaki (# 1116).

\subsection*{Equipment}

Eating movements were measured using a three-dimensional (3D) motion analysis system with inertial sensors (Xsens Technologies B.V., Enschede, The Netherlands; MVN).\textsuperscript{23} The small inertial sensors (MTx and MTx-L) of this motion system had built-in 3D linear accelerometers, 3D rate gyroscopes, and 3D magnetometers. Using the Lycra suit and gloves (selected from five sizes to match to participant’s height) and the headband and foot mounts supplied with this system, 17 small inertial sensors were placed on each participant’s head, hands, forearms, upper arms, scapulae, sternum, pelvis, upper legs, lower legs, and feet (Fig. 1). Sensor data related to the position and orientation of each body segment were sampled at 120 Hz and were transmitted to a personal computer via a wireless LAN connection using transmitters (Xbus Master) and receivers (WR-A). Dedicated software (Xsens Technologies B.V., Enschede, The Netherlands; MVN Studio 3.1)\textsuperscript{23} was used to calculate each participant’s motion data based on their body dimensions and to achieve data fusion and segment calibration. This system was also capable of recording synchronized motion and video data using an MVN Ethernet camera. In this system, the human model of the full body configuration has 23 body segments, each defined so that it conforms as much as possible to the origins and axes recommended by the International Society of Biomechanics.\textsuperscript{24} However, one neck, four spine, and two toe segments were not measured directly but were calculated. Joint rotation of the human model was defined by the position of the distal body segments relative to the proximal body segments. The neutral position of the human model, i.e., the zero position of the joint angles, was the anatomical position with the participants standing upright, feet parallel (one foot-width apart) with arms straight alongside the body and the palms of the hands facing forward.
The utensils used for eating in this study were a metallic spoon (length, 17.5 cm; weight, 41 g), wooden chopsticks (length, 22.5 cm; weight, 8 g), and a ceramic dish (diameter, 15.5 cm; depth, 4.5 cm; weight, 246 g). The food items used were yogurt (for the spoon activity) and sliced vegetables pickled in soy sauce (for the chopstick activity). These items were chosen because the basic motions applied when eating these foods appear to be common to the motions applied when eating various other food items.

**Fig. 1.** A participant wearing the MVN Lycra suit, gloves, headband, and foot mounts with the 17 inertial sensors of the three-dimensional motion analysis system. The positions of the inertial sensors are indicated by arrows. (a) Rear view, (b) right-side view.
Procedures

All measurements were performed at our institution. The participants put on the Lycra suit, headband, gloves, and foot mounts, and 17 small inertial sensors and two transmitters were fixed in place. It was confirmed that the Lycra suit, headband, gloves, and foot mounts appropriately fitted the participants and that participants could comfortably move in response to oral commands and in such a way as to allow visual observation. After calibration, we measured each participant’s dimensions and entered the data into the dedicated software. Next, the participant adopted an upright sitting position on a 40-cm stand in front of a table, and we adjusted the near edge of the table to be 10 cm from the participant’s trunk and the height of the top of the table to be at the height of the participant’s olecranon. A ceramic dish containing food was placed on the table in alignment with the midline of the participant in the sagittal position at a distance corresponding the participant’s right middle finger tip with the participant in the measurement preparation position. The measurement preparation position was the right elbow at a joint flexion of 90° with the right forearm joint in the neutral position of pronation and supination, the right fingers stretched, the right shoulder joint and wrist joint in the anatomical position, and the left hand placed on the left upper leg. Participants adopted a comfortable position of the head, neck, trunk, and both lower limbs. Each eating task involved reaching the dish with the utensil, scooping or picking up food from the dish, bringing the food to the mouth, and taking food off the utensil and was performed with a comfortable motion and at a comfortable pace (Fig. 2, 3). The motion was performed three times consecutively because we considered that the first and last motions might not represent complete natural eating cycles (e.g., the first eating cycle may involve partial reaching from the table to the dish and the final eating cycle may involve holding the utensil in the mouth) and should therefore not be analyzed. The first task involved eating yogurt from a dish using a spoon held freely in the right hand. All participants naturally held the spoon using the pen grasp in the same manner without being instructed about the standardized method (Fig. 2). The second task involved eating sliced vegetables pickled in soy sauce using wooden chopsticks held freely in the right hand. All participants naturally held one chopstick with the index finger, the middle finger, and the thumb (as one would hold a pencil) and the other chopstick between the bottom of the thumb and the tip of the ring finger in the same manner without being instructed about the standardized method (Fig. 3).

The complete eating cycles using chopsticks and using a spoon consisted of reaching the dish with the utensil, scooping or picking up food from the dish, bringing the food to the mouth, and taking food off the utensil. We extracted motion data from soon after a participant first took food into the mouth and the utensil left the mouth to just before the participant again took food into the mouth and the utensil left the mouth for the second time. We determined the start and finish times of these motions by visually observing and manually selecting a still frame at those moments from the video data synchronized using an MVN Ethernet camera. Microsoft Excel 2013 (Microsoft Corporation, WA, USA) was used for presenting motion data. To evaluate the upper limb joint angles, we determined the maximum and minimum right shoulder joint abduction, flexion, and internal rotation angles, the elbow joint flexion angle, the forearm joint pronation angle, and the wrist joint radial flexion and...
extension angles in the human model.

**Data Analyses and Statistical Tests**

The present study design comprised two independent groups of men and women. The means and standard deviations of the maximum joint angles and the RoMs of the joints (RoMs were the differences between the maximum and minimum joint angles) were calculated separately for men and women. Cohen’s $d$ as the effect size was calculated to standardize the differences in the means of the two independent groups. A Cohen’s $d \geq 0.8$ was set as a large effect size. The joint angle in the human model was calculated for the shoulder joint between the scapula and the upper arm, for the elbow and forearm joint between the upper arm and forearm, and for the wrist joint between the forearm and hand.

For statistical comparisons of joint angles in men and women, the data were tested for normality using the Shapiro–Wilk test, and normally distributed variables were tested for homoscedasticity using the Levene test. Variables identified as being homoscedastic were compared using independent $t$-tests, and the other variables were compared using the Welch test. Non-normally distributed variables were compared using the Mann–Whitney $U$ test. All significance levels were set at $P <0.05$. For all statistical tests, we used IBM SPSS Version 20 (IBM Corp., Armonk, NY, USA).

**RESULTS**

**Using a Spoon**

The maximum upper limb joint angles for men and women during the spoon task and the results of the associated statistical tests and Cohen’s $d$ are presented in table 1. The maximum elbow joint flexion angle was significantly greater in women than in men with a large effect size. The maximum shoulder joint internal rotation angle showed a large effect size. There were no significant differences between men and women in terms of other maximum joint angles.

**Using Chopsticks**

The maximum upper limb joint angles for men and women during the chopstick task and the results of statistical tests and Cohen’s $d$ are presented in table 3. The maximum shoulder joint internal rotation and the elbow joint flexion angles were found to be significantly greater in women than in men, with large effect sizes. In contrast, the maximum wrist joint radial flexion angle was observed to be significantly greater in men than in women, with a large effect size. No significant differences were observed between men and women in terms of the other maximum joint angles. The RoMs of the upper limb joints and the results of statistical tests and Cohen’s $d$ for the chopstick task are given in table 4. All the RoMs of the joints were numerically greater in women than in men; however, the difference was only statistically significant, with a large effect size, for shoulder joint abduction.
In the present study, we first established the maximum RoM of the upper arm joints in men and women in an eating task involving the use of a spoon. There were statistically significant gender differences and large effect sizes. In a recent study that used an optical motion capture system, the maximum elbow joint flexion angle during eating with a spoon, which involved data for men and women,9) showed high correspondence with our findings for men, with a difference of 0.4°, thereby partially validating our experimental setup and procedures. Our findings for the maximum shoul-

**Table 1. Maximum upper limb joint angles for men and women during the spoon task**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Direction of Motion</th>
<th>Mean Maximum Joint Angle (°)</th>
<th>Significance</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Men (n=12)</td>
<td>Women (n=13)</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Abduction</td>
<td>35.4 ± 8.2</td>
<td>36.3 ± 8.7</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Flexion</td>
<td>39.0 ± 8.2</td>
<td>40.0 ± 8.4</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Internal Rotation</td>
<td>8.8 ± 11.3</td>
<td>17.4 ± 10.2</td>
<td>n.s.c</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion</td>
<td>125.0 ± 11.5</td>
<td>133.4 ± 7.5</td>
<td>P &lt; 0.05b</td>
</tr>
<tr>
<td>Forearm</td>
<td>Pronation</td>
<td>95.2 ± 21.6</td>
<td>111.8 ± 21.0</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Wrist</td>
<td>Radial Flexion</td>
<td>2.5 ± 12.0</td>
<td>3.9 ± 11.6</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Wrist</td>
<td>Extension</td>
<td>35.6 ± 10.1</td>
<td>37.5 ± 8.1</td>
<td>n.s.a</td>
</tr>
</tbody>
</table>

n.s., not significant.

aIndependent t-test (df=23); bWelch test; cMann–Whitney U test.

**Table 2. Range of motion of the upper limb joints for men and women during the spoon task**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Direction of Motion</th>
<th>Mean RoM of the Joint (°)</th>
<th>Significance</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Men (n=12)</td>
<td>Women (n=13)</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Abduction</td>
<td>9.4 ± 6.1</td>
<td>17.1 ± 6.3</td>
<td>P &lt; 0.05a</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Flexion</td>
<td>21.2 ± 12.1</td>
<td>31.1 ± 8.4</td>
<td>P &lt; 0.05a</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Internal Rotation</td>
<td>11.6 ± 6.3</td>
<td>17.3 ± 6.7</td>
<td>P &lt; 0.05a</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion</td>
<td>32.4 ± 8.4</td>
<td>35.3 ± 7.2</td>
<td>n.s.c</td>
</tr>
<tr>
<td>Forearm</td>
<td>Pronation</td>
<td>76.9 ± 15.9</td>
<td>79.7 ± 17.9</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Wrist</td>
<td>Radial Flexion</td>
<td>14.0 ± 6.4</td>
<td>20.8 ± 11.3</td>
<td>n.s.b</td>
</tr>
<tr>
<td>Wrist</td>
<td>Extension</td>
<td>13.4 ± 4.3</td>
<td>16.0 ± 6.1</td>
<td>n.s.c</td>
</tr>
</tbody>
</table>

n.s., not significant.

aIndependent t-test (df=23); bWelch test; cMann–Whitney U test.

**Table 3. Maximum upper limb joint angles for men and women during the chopstick task**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Direction of Motion</th>
<th>Mean Maximum Joint Angle (°)</th>
<th>Significance</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Men (n=12)</td>
<td>Women (n=13)</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Abduction</td>
<td>31.1 ± 7.4</td>
<td>30.0 ± 6.1</td>
<td>n.s.c</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Flexion</td>
<td>27.4 ± 5.3</td>
<td>22.7 ± 9.4</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Internal Rotation</td>
<td>0.8 ± 9.0</td>
<td>10.0 ± 8.9</td>
<td>P &lt; 0.05c</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion</td>
<td>127.0 ± 9.7</td>
<td>137.0 ± 8.3</td>
<td>P &lt; 0.05a</td>
</tr>
<tr>
<td>Forearm</td>
<td>Pronation</td>
<td>90.1 ± 14.5</td>
<td>104.0 ± 22.1</td>
<td>n.s.a</td>
</tr>
<tr>
<td>Wrist</td>
<td>Radial Flexion</td>
<td>9.0 ± 7.8</td>
<td>−1.0 ± 8.2</td>
<td>P &lt; 0.05a</td>
</tr>
<tr>
<td>Wrist</td>
<td>Extension</td>
<td>31.6 ± 10.1</td>
<td>31.7 ± 12.3</td>
<td>n.s.a</td>
</tr>
</tbody>
</table>

n.s., not significant.

aIndependent t-test (df=23); bWelch test; cMann–Whitney U test.
under joint flexion, elbow joint flexion, and wrist joint radial flexion angles and the RoMs of the shoulder joint internal rotation, forearm joint pronation, and wrist joint extension for men when using a spoon were similar to those reported by Safaee-Rad et al.\textsuperscript{16}) with differences of less than 5°. However, the maximum shoulder joint abduction, internal rotation, forearm joint pronation, and wrist joint extension angles and the RoMs of shoulder joint abduction and flexion, elbow joint flexion, and wrist joint radial flexion were not similar to those reported by Safaee-Rad et al.\textsuperscript{16}) with differences of more than 5°. We believe that these differences occurred because of the use of different measuring apparatus and differences in the participants’ postures between our study and the previous study.

For women using a spoon, our findings of the maximum elbow joint flexion angle were similar to those reported by Magermans et al.\textsuperscript{21}) with a difference of 1.9°. However, our findings of the maximum forearm joint pronation angle were not similar to those reported by Magermans et al.\textsuperscript{21}) with a difference of 39.9°. We believe that the cause of this difference was the use of different measuring apparatus and different eating tasks. In particular, the present eating task used a spoon with actual food, whereas the previous eating task used a spoon without food.

In the present study, we also conducted a task to establish the maximum RoM of the upper arm joints when using chopsticks. In this task, we noted significant gender differences and large effect sizes. For women using chopsticks, our findings of the elbow joint flexion RoM were similar to those reported by Nishimura et al.\textsuperscript{22}) with a difference of 1.7°. However, our findings of the maximum elbow joint flexion and forearm joint pronation angles and of the forearm joint pronation RoM were not similar to those reported by Nishimura et al.\textsuperscript{22}) with differences greater than 22°. We believe that these differences occurred because of the use of different measuring apparatus and differences in the participants’ postures between our study and the previous study.

Gender differences in movements could result from differences in body size, physique, supporting tissues, muscle strength, and cultural factors, such as clothes and footwear.\textsuperscript{26}) In the present study, because the positional relationship variations were adjusted for body size to maintain uniformity, we believe that the influence of body size was likely negligible. Therefore, we consider that other physique-related and cultural factors influenced the gender differences identified in the present study. The range of neck and trunk motion during eating may regulate the range of upper extremity motion. Findings from a previous study suggested that the range of head forward inclination, include RoMs of the neck and trunk, during realistic eating were significantly smaller in women than in men.\textsuperscript{19}) This may be a contributing factor to the larger range of upper extremity motion in women than in men found in the present study.

In the present study, because all the RoMs of the joints were numerically greater in women than in men, it is likely that upper limb movement during normal eating is generally greater in women than in men. Statistically, we recognized that gender differences in the maximum elbow joint flexion angle and RoMs of shoulder joint abduction and flexion were approximately 10° and that of the RoM of the shoulder joint internal rotation was approximately 5° with the subject using a spoon. Additionally, when the subjects used chopsticks, we found that gender differences in the maximum shoulder joint internal rotation, elbow joint flexion, and wrist joint radial flexion angles were approximately 10° and that of the RoM

### Table 4. Range of motion of the upper limb joints for men and women during the chopstick task

<table>
<thead>
<tr>
<th>Joint</th>
<th>Direction of Motion</th>
<th>Mean RoM of the Joint (°)</th>
<th>Significance</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Men (n=12)</td>
<td>Women (n=13)</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Abduction</td>
<td>6.6 ± 2.0</td>
<td>10.3 ± 5.7</td>
<td>P &lt; 0.05\textsuperscript{b}</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Flexion</td>
<td>12.6 ± 4.1</td>
<td>15.5 ± 7.2</td>
<td>n.s.\textsuperscript{a}</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Internal Rotation</td>
<td>10.1 ± 4.2</td>
<td>10.9 ± 4.9</td>
<td>n.s.\textsuperscript{a}</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion</td>
<td>31.3 ± 8.1</td>
<td>34.7 ± 7.0</td>
<td>n.s.\textsuperscript{a}</td>
</tr>
<tr>
<td>Forearm</td>
<td>Pronation</td>
<td>75.3 ± 7.6</td>
<td>79.0 ± 12.7</td>
<td>n.s.\textsuperscript{a}</td>
</tr>
<tr>
<td>Wrist</td>
<td>Radial Flexion</td>
<td>10.6 ± 5.6</td>
<td>13.5 ± 5.9</td>
<td>n.s.\textsuperscript{c}</td>
</tr>
<tr>
<td>Wrist</td>
<td>Extension</td>
<td>15.4 ± 6.0</td>
<td>20.8 ± 9.7</td>
<td>n.s.\textsuperscript{c}</td>
</tr>
</tbody>
</table>

n.s., not significant.

\textsuperscript{a}Independent t-test (df=23); \textsuperscript{b}Welch test; \textsuperscript{c}Mann–Whitney U test.
of the shoulder joint abduction was approximately 5°. We consider that these numerical values can be used for clinical observation and manipulation using goniometers.

Previous studies have reported joint angles during eating with a spoon for men and women10,16,20,21) and during eating with chopsticks for women,22) but gender differences were not investigated. Our findings identified that upper limb joint angles and RoMs of joints during eating differ between genders, which contrasts with the findings of previous studies.

The present study has some limitations. The study sample size was rather small, and many differences in joint angles and RoMs were not found to be statistically significant, which may have resulted from type II errors. Although the error in the measurements of the inertial sensors in our study was small to negligible, the inertial sensors were not directly attached to the participants’ skin but were fixed in the suit and gloves (matched to the participants’ body heights) and in the headband and foot mounts worn by the participants. Therefore, it is possible that the inertial sensors might have slipped out of place because of the movement of participants. This artifact might have caused data errors in our study. In the present study, eating activities were performed in an experimental environment, and this does not practically replicate the usual way of eating in clinical practice or in daily living, which varies among individuals and under different situations. Consequently, the results may need to be adapted for a clinical environment. Because the participants in the study were young, healthy Japanese adults, care is required when applying the results to non-Japanese, late middle-aged, or older individuals. Moreover, some people hold spoons and chopsticks with different grips, such as the handshake grip or the underhand grip. Consequently, if the upper limb joint angles, RoMs, and their gender differences are investigated during eating with different grips, the results will not be directly comparable with our findings.

CONCLUSION

In the present study, we identified significant gender differences with respect to joint angles and RoMs during eating in young, healthy Japanese adults. We believe that numerous factors may be responsible for gender differences in the upper limb joint angles during eating. Therefore, future studies should focus on elucidating these factors and the changes in upper limb joint angles through the process of gender-segregated eating.

ACKNOWLEDGMENTS

We thank Shinya Nagata, Shogo Maeda, and Tomoyuki Kobayashi who assisted with this study. This work was supported in part by a grant from the Program to Disseminate Tenure Tracking System from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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