Introduction

A registered occupational therapist (OTR) uses assistive technology (AT) to improve a person’s activities of daily living (ADL) and instrumental activities of daily living. In AT, the input system of humans is used for visual, auditory, and somatosensory disorders. The output system of humans is used for upper extremity motion, finger motion, lower extremity motion, and trunk motion disorders (Demain et al., 2013; McIntyre & Atwal, 2005). Moreover, AT is used for mental disorders, higher brain dysfunction, and developmental disorders. However, the AT framework is provided according to its intended purpose. For example, AT support has a communication board and a speech generating device for people with speech, language, and hearing disorders (McIntyre & Atwal, 2005; Pedretti & Early, 2001; Willard et al., 2009).

Eating and toilet hygiene are initial ADL acquisition targets of subjects with disabilities resulting from injuries such as head or spinal cord injuries. Eating and toilet hygiene are the goals of early ADL acquisition. Especially, acquisition of eating is important not only because of life support, but also for individual and social pleasure. A meal support robot (My Spoon, MA-R0010; SECOM, Inc., Tokyo) is an electrical eating device for people who have limited functionality of their arms or hands, and serves as one AT device (Soyama, Ishii & Fukase, 2003). A user with rheumatoid arthritis, cervical cord injury, or muscular dysplasia can operate My Spoon using a joystick or a button switch. Using My Spoon, one can choose food in a voluntary order with voluntary timing. Reportedly, the use of My Spoon improves the quality of life (QOL) and independent ADL.

Because of head and spinal cord injuries, simple motions such as carrying food from a plate to the mouth cannot be done smoothly. An OTR must teach proper eating motions. However, subjects desiring smooth eating motion cannot use My Spoon alone. For such
cases, an OTR must offer support when introducing My Spoon. An OTR must understand the characteristics of AT when instructing subjects (Goto, Hatakeyama & Katayama, 2008). It is therefore important that the OTR know the physiological and psychological effects of AT on the subjects.

This study examines differences of the visual axis and pupil diameter between unassisted eating and robot-assisted eating in healthy subjects, in addition to their respective physiological responses.

Methods

Subjects

Subjects were 12 healthy volunteers (5 males, 7 females) from 20–26 years old (mean 22; standard deviation 2). All subjects had visual acuity necessary to obtain a driver’s license, color sense, right-handedness, and affiliated psychic function. None had any disease or injury that would impair ADL. All subjects gave their informed consent to the experimental procedures, which were approved by the Ethics Committee of Yamagata Prefectural University of Health Sciences, Yamagata, Japan.

Instrumentation and Data Acquisition

Exploratory eye movements were recorded using an eye tracker (EMR-8B; nac Image Technology Inc., Tokyo) with a sampling frequency of 30 Hz, which detects infrared reflections from the cornea. EMR-8B consisted of an eye camera head unit attachment and a controller. The eye camera head unit includes a pupil camera and a field camera. A visual axis position was attached to a picture from the field camera with the controller. The field camera of the head unit did not have a skewness of lens and used lens of diameter 62 degrees (deg) that a wide image was obtained. The detection precision of upper extremity motion on the desk of the subjects was 0.2 deg of 40 deg inside the circle of the cycloduction axis. A digital video camera (30 frames per second, NV-GS320; Panasonic Inc., Osaka) was set outside the subjects. Data were recorded using a digital motion picture waveform real-time synchronous recording system (The Teraview; Gigatex Co. Ltd., Osaki). Meal tools were a spoon (stainless steel, 180 mm full length) and a My Spoon.

My Spoon has the following characteristics; a base, an arm and a hand part (with the spoon and fork). My Spoon dimensions are 370 mm deep, 280 mm wide, and 250 mm high, with a weight of 6.0 kg. My Spoon has a plate (245 mm deep, 245 mm wide, 58 mm high) divided into four sections. A user can easily operate My Spoon with the joystick. There are three types of operation modes; automatic, semi-automatic, and manual. This experiment used the manual mode of My Spoon with the joystick.

Procedures

Illumination in the test room was 652 lux, and the air temperature was about 24°C. The subjects sat on a chair (400–450 mm height) and put the forearm on a table (800 mm deep, 1,200 mm wide, 700 mm high) with the shoulders flexed to 0–20 deg of flexion and the elbow flexed to 70–90 deg of flexion. The subjects held the spoon or the joystick for the eating task prior to task commencement (Fig. 1). The respective distances between the mouth and the plate during unassisted eating and robot-assisted eating were 338–471 mm and 321–577 mm. The food used in the experiment was a doughnut-type cereal (Kokokun-no-chocowa; Kelloggs Co., Tokyo) 15 mm in diameter. The eyes of the subjects were masked to prevent the intervention of prior visual information. Visual masking was removed at the start of the eating task. When food was in the mouth of the subjects, the task was finished. Subjects were allowed to spit out the food from their mouths if they did not want to swallow it. A bowl for this was prepared beside the subjects. The eating tasks were unassisted eating and robot-assisted eating.

Unassisted eating procedure

For unassisted eating, subjects were instructed to eat food in the same way as in daily life. Types of motion, speed, and accuracy were not instructed to any subject.

Robot-assisted eating procedure

My Spoon was set at about 300 mm in front of the subjects. The center of the My Spoon plate was aligned with the midline of the subjects. The spoon tip of My Spoon was set to stop at about 50 mm to 100 mm from the mouth of each subject. When the spoon of My Spoon neared the subjects’ mouths, the subjects showed some anxiety. Each subject set a distance of 50–100 mm for which it was easy to eat without anxiety. Next, the subjects performed three to five practice exercises to test the joystick operation of My Spoon. The subjects chose the food from any of four sections using the joystick, and the robot arm moved the section chosen by the subject. The subjects then maneuvered the hand part of My Spoon to the food. The robot caught the food in the spoon which was attached to the hand part, and moved it toward the mouth. Finally, the subject ate the food from the spoon. The subject operated the joystick during the start of task, while controlling the spoon position on the
Data Analysis

1. Motion Phases

Unassisted eating

Phases of each eating task were divided into three phases using video data. During phase 1 (P1), the spoon began moving and reached the food. During phase 2 (P2), the spoon picked up the food. During phase 3 (P3), the spoon moved from the plate to the mouth of the subjects (eating motion).

Robot-assisted eating

During P1, the spoon attachment of My Spoon moved and arrived on the plate. During P2, the spoon attachment controlled the spoon position and picked up the food. The phase ended before My Spoon began to move the spoon to the mouth of the subjects. During P3, the spoon attachment moved the spoon to within 50–100 mm of the front of the mouth, arrived at the mouth, and the subjects put the food into the mouth.

2. Classification of eye movement

The position of the visual axis was fed to a picture from a field camera, and pursued during the eating task. Furthermore, the eye movements were classified into three types; saccadic eye movements (SEM), smooth pursuit eye movements (SPEM), and fixation. SEM were determined to be eye movement of an angle speed greater than 50 deg/s. SPEM were determined to be eye movements which follow the food at an angle speed of less than 50 deg/s (Fukushima & Fukushima, 2004; Tazaki & Saito, 2013). Fixation was defined as inactive eye movements which continued longer than 0.10s (Manor & Gordon, 2003). Therefore, the eye mark was paused at the same position for more than three field camera images under these conditions.

3. Visual axis position and upper extremity motion

The visual axis position was divided into three categories; showing a plate and section with food; showing the spoon on the spoon bowl without the food, and showing the food. Other positions showed blinking and/or no placement of the plate, the spoon, the food. The Critical Visual Point (CVP) was defined as the upper extremity position at which the visual axis was removed from the food in P3.

4. Pupil diameter

The pupil diameter was measured at 30 Hz using Eye mark data analysis software (EMR-dFactory; nac Image Technology Inc. Tokyo). The pupil diameter of each subject was measured before and after the near reflex test. The reference of pupil diameter used the difference of the before and after the near reflex test (Tazaki & Saito, 2013). Judgment of three types of change in P3 was made; increase, decrease, or no change. The pupil diameter change in all trials included each type. The quantity of change of the pupil diameter was calculated the difference between the maximum and the minimum (min-to-max or max-to-min) of P3.
Results

Fig. 2 shows the respective transitions of the visual axis and the pupil diameter during unassisted eating for subject A. The spoon arrived at the food within 0.9 s from the task start (end of P1). The visual axis of the subject was on the food. Furthermore, the subject picked up the food with the spoon in 3.0 s (end of P2). During P2, the visual axis changed in order of the food, the spoon, and back to the food. Next, the spoon began to move toward the mouth and arrived at the mouth within 4.8 s from the task start (end of P3). In P3, CVP occurred at 3.9 s from the task start. CVP was 0.9 s from start of P3. The spoon at this time was located 221 mm from the left eye of the subject.

The order of the visual axis position with other trial was different. However, the eye movement patterns were similar to those shown by this subject. Furthermore, all subjects showed the same visual axis positions and eye movement patterns.

The visual axis of P1 was fixed on the food from task start to 0.3 s later. The visual axis was fixated on the food thereafter for 0.6 s. At that moment, the pupil diameter increased 0.5 mm; from 2.8 mm to 3.3 mm. During P2, the eye movement pattern changed in order of fixation (0.2 s duration), SPEM (0.6 s), fixation (1.0 s), and SPEM (0.3 s). In addition, SEM occurred between fixation and SPEM. The pupil diameter increased 0.7 mm; from 3.3 mm to 4.0 mm. During P3, the eye movement pattern changed in order of SPEM (0.6 s), SPEM (0.4 s), fixation (0.5 s), others (0.2 s), and fixation (0.1 s). The pupil diameter did not change. In the subject, the pupil diameter showed changes similar to other trials in P1-P2. However, this subject showed an increase in pupil diameter among five trials, a decrease in two trials and no change in three trials in P3 (Table 3).

Fig. 3 shows the respective transitions of the visual axis and the pupil diameter during robot-assisted eating for subject A. The spoon of the hand attachment arrived at the plate at 7.9 s from the task start (end of P1).

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Fig. 2. Transition of visual axis and the pupil diameter during unassisted eating in the subject A

The figure shows digital video camera images (DVC), field camera images (FC), the position of visual axis (VA) and pupil diameter (PD). Slash line boxes of FC show fixation of eyes. Dotted boxes of FC show smooth pursuit eye movement. Black color boxes show saccadic eye movement. When the visual axis was located in the blank part in all phases, it was others. DVC and FC show the start of task, end of Phase 1, end of Phase 2, critical visual point (CVP), and end of task sequentially from the left. Left dotted line shows the task start. Dotted lines of P1, P2, and P3 show the end of each phase. The broken line shows CVP. Abbreviations are the same as those shown in Fig. 3.
During P1, the visual axis position shuttled back and forth among the plate, the spoon, the food, and other objects. Furthermore, the subject controlled the spoon to accommodate the food, and picked up the food with the spoon in 14.7 s (end of P2). During P2, the visual axis position changed in the following order; the spoon, the food, the plate, the spoon, the food, other objects, the food, the spoon, and the food. Next, the spoon began to move toward the mouth and arrived 97 mm from the mouth front within 23.4 s from the task start. The subject put the food in the mouth within 25.9 s from the task start (end of P3). The visual axis position was fixed only on the spoon during P3. The spoon at this time was located 152 mm from the left eye of the subject.

The order of the visual axis position differed from those of other trials. However, the visual axis positions and the eye movement patterns were similar to those shown by this subject. During P3, the visual axis position was on the spoon and the plate in some of the trials of the 10 subjects. Furthermore, all subjects showed the same visual axis position from P1 to P3 as that of this subject.

The visual axis of P1 was fixed on the food from the task start to about 0.3 s later. During P1, the eye movement fixation times were 0.1−0.3 s on the plate and 0.3−1.8 s on the food. Moreover, the eyes were fixated on the spoon at 0.5−0.6 s, and 0.9 s of SPEM. During this time, the visual axis position shuttled back and forth among the plate, the spoon and the food. At that moment, the pupil diameter increased 0.9 mm; from 3.0 mm to 3.9 mm. During P2, the eye movement pattern showed only fixation, which occurred eight times. Each fixation time was 1.1 s on the plate, 0.3−1.6 s on the spoon, and 0.2−0.7 s on the food. The pupil diameter increased 0.8 mm; from 3.7 mm to 4.5 mm. During P3, the visual axis position was only on the spoon. The eye movement patterns were fixation, SPEM, and SEM. The fixation time showed 0.2−0.8 s. Furthermore, the SPEM time showed 0.3−1.2 s only on the spoon. The pupil diameter decreased 1.7 mm; from 4.5 mm to 2.8 mm, which was similar to that of other trials for this subject. In all trials, this subject showed a decreased pupil diameter in P3 (Table 4).

Table 1 shows the elapsed times in respective phases and CVP times for unassisted eating in all subjects. The range of total elapsed time was 2.2−4.0 s in all subjects. The elapsed times of each phase were 0.8−1.3 s, 0.5−1.1 s, and 0.9−1.8 s. All trials of all subjects had a CVP in P3. The range of CVP times from the start of P3 was 0.5−1.1 s.

Table 2 shows the elapsed times in respective phases for robot-assisted eating in all subjects. The range...
of total elapsed times was 24.7–27.2 s. Furthermore, the elapsed times of each phase were 7.8–8.9 s, 5.0–6.9 s, and 10.4–12.9 s. In all subjects, CVP disappeared completely from all trials in P3.

Table 3 shows the min-to-max or max-to-min pupil diameters, differences, and changing counts for unassisted eating in all subjects of P3. For subject A, the min-to-max or max-to-min pupil diameters increased from 3.8 to 4.1 mm, decreased from 4.2 to 3.9 mm, and remained unchanged at 3.9 mm. The pupil diameter difference was a 0.3 mm increase and a 0.3 mm decrease. The increase, decrease, and no change of pupil diameters were 5, 2 and 3, respectively. The near reflex value was 1.1 mm; from 3.8 mm to 2.7 mm. Five subjects showed an increase, decrease, and no change of pupil diameters. The pupil diameter changing counts showed increase of two and decrease of eight. The near reflex value was 1.2 mm; from 4.5 mm to 3.2 mm. Two subjects showed an increase and decrease of pupil diameter.

In subject H, the min-to-max pupil diameters increased from 4.2 to 4.6 mm. The difference of pupil diameter was 0.4 mm. The pupil diameter increased in all trials. The near reflex value was 1.8 mm; from 5.1 mm to 3.3 mm. Two subjects showed an increase in pupil diameter.

In subject J, the max-to-min pupil diameters decreased (from 5.2 to 4.3 mm). The difference of pupil diameter showed a 0.9 mm decrease. The pupil diameter decreased in all trials. The near reflex value was 1.9 mm; from 4.5 mm to 2.6 mm. Three subjects showed a decrease in pupil diameter.

Table 4 shows the pupil diameters from min-to-max or max-to-min, difference and changing counts in robot-assisted eating of all subjects in P3.

In subject A, the max-to-min pupil diameters decreased from 4.4 to 2.9 mm. The difference of pupil diameter was 1.5 mm. A decrease in pupil diameters appeared in all trials of all subjects.

**Discussion**

**Characteristics between visual axis and pupil diameter during unassisted eating**

Fig. 2 shows that the visual axis was placed only on the spoon and the food from task start to CVP. The pupil diameter increased slowly from task start to the end of P2. In addition, the pupil diameter at P3 increased slightly with CVP. The subject in Fig. 2 showed three types of pupil diameter transitions; increase, decrease, and no change (Table 3). However, the difference of pupil diameter in each type was less than the near reflex.
A near reflex test is an examination to look at about 100 mm front of a subject immediately from a far-off place. The pupil diameter decreases in healthy subjects. The phenomenon results from an accommodation reflex and a convergence reflex (Bando, 1996; Leigh & Zee, 1991). The near reflex differs from light reflex in terms of path-ways (Tazaki & Saito, 2013). The CVP of the subject was more distant than the near reflex. Reportedly, the recorded distances of CVP in the 19 subjects were large among the subjects, ranging from 157−471 mm in the performance of 0.1 spoon. The CVP distance of each subject was reduced slightly when the amount of juice in the spoon was increased (Sasaki et al., 2013).

Two subjects showed both an increase and decrease. Three subjects showed only a decrease. In addition, the difference of pupil diameters was smaller than the near reflex in each subject. A recent report described that CVP occurs in eating motions using a spoon and chopsticks (Nito, 2011). The report suggests that the role of the visual axis to the CVP reflected monitoring of the food during eating motions. However, other reports described that the motion carrying the spoon with the juice did not need to constantly maintain the visual axis on the cup of the spoon (Suzuki, Fujii & Nikara, 2009; Table 3.

| Subject | Pupil diameter (mm) | Near reflex (mm) |
|---------|---------------------|------------------|
|         | Max (Min) to Min (Max) | Type | Dif. | Counts | Max | Min | Dif. |
| A       | 3.8-4.1             | Inc | 0.3 | 5     | 3.8 | 2.7 | 1.1 |
|         | 4.2-3.9             | Dec | 0.3 | 2     | 4.9 | 3.4 | 1.5 |
| B       | 5.8-5.9             | Inc | 0.1 | 2     | 4.6 | 2.7 | 2.1 |
|         | 6.2-5.8             | Dec | 0.4 | 4     | 4.4 | 2.7 | 1.7 |
| C       | 4.5-4.6             | Inc | 0.1 | 6     | 4.5 | 5.7 | 2.0 |
|         | 4.7-4.5             | Dec | 0.2 | 2     | 4.8 | 5.7 | 0.9 |
| D       | 5.2-5.4             | Inc | 0.2 | 5     | 4.9 | 3.4 | 1.5 |
|         | 5.5-5.1             | Dec | 0.1 | 3     | 4.6 | 3.4 | 1.2 |
|         | 5.5-5.1             | No  | 0.0 | 2     | 4.4 | 3.2 | 1.2 |
| E       | 3.6-3.7             | Inc | 0.1 | 2     | 3.7 | 3.5 | 0.2 |
|         | 3.7-3.5             | Dec | 0.2 | 7     | 3.4 | 3.2 | 1.1 |
| F       | 3.6-3.7             | Inc | 0.1 | 2     | 3.9 | 3.6 | 0.3 |
|         | 3.9-3.6             | Dec | 0.3 | 8     | 3.7 | 3.6 | 1.1 |
| G       | 4.3-4.4             | Inc | 0.1 | 2     | 4.2 | 4.2 | 0.0 |
|         | 4.3-4.2             | Dec | 0.1 | 3     | 4.1 | 3.7 | 0.4 |
| H       | 4.2-4.6             | Inc | 0.4 | 10    | 4.6 | 4.2 | 0.4 |
|         | 4.6-4.2             | Dec | 0.2 | 0     | 4.5 | 3.3 | 1.2 |
| I       | 4.8-5.1             | Inc | 0.3 | 10    | 4.9 | 3.8 | 1.1 |
|         | 4.9-3.6             | Dec | 0.1 | 0     | 4.5 | 3.8 | 0.7 |
| J       | 5.2-5.4             | Dec | 0.9 | 10    | 5.0 | 3.1 | 1.9 |
|         | 5.2-5.4             | No  | 0    | 0     | 4.5 | 3.1 | 1.4 |
| K       | 5.4-5.0             | Dec | 0.4 | 10    | 5.3 | 3.6 | 1.7 |
|         | 5.5-5.0             | No  | 0    | 0     | 5.0 | 3.6 | 1.4 |
| L       | 4.0-3.6             | Dec | 0.4 | 10    | 3.5 | 2.6 | 0.9 |
|         | 4.0-3.6             | No  | 0    | 0     | 3.3 | 2.4 | 0.9 |
Suzuki et al., 2011). Therefore, the motion carrying the spoon is mainly performed using a motor program that is readily acquired in the brain. In addition, a recent study using dominant and non-dominant hands has shown that CVP had the same role as the eating motion (Takahashi, 2013). The report implied that CVP affects monitoring with a conscious guide of food. However, the relation of the visual axis and pupil diameter during eating motions has not previously been reported. These findings suggest that the pupil diameter transition during fixation on the visual axis of a spoon is not only done in the monitoring of the food.

**Table 4. Pupil diameter of robot-assisted eating in phase 3**

| Subject | Pupil diameter (mm) | Near reflex (mm) |
|---------|---------------------|-----------------|
|         | Max (Min) to Min (Max) | Type | Dif. | Counts | Max | Min | Dif. |
| A       | 4.4 - 2.9 Inc | 1.5 | 10 | 3.8 | 2.7 | 1.1 |
| B       | 6.1 - 4.6 Dec | 1.5 | 10 | 4.9 | 3.4 | 1.5 |
| C       | 4.2 - 3.0 Dec | 1.2 | 10 | 4.8 | 2.7 | 2.1 |
| D       | 5.6 - 3.9 Dec | 1.7 | 10 | 4.4 | 3.2 | 1.2 |
| E       | 3.6 - 2.8 Dec | 0.8 | 10 | 3.4 | 2.3 | 1.1 |
| F       | 3.9 - 3.1 Dec | 0.8 | 10 | 3.2 | 2.7 | 0.5 |
| G       | 4.9 - 3.2 Dec | 1.7 | 10 | 4.5 | 3.2 | 1.3 |
| H       | 5.4 - 3.7 Dec | 1.7 | 10 | 5.1 | 3.3 | 1.8 |
| I       | 5.2 - 3.4 Dec | 1.8 | 10 | 4.3 | 3.4 | 0.9 |
| J       | 4.9 - 2.9 Dec | 2.0 | 10 | 4.5 | 2.6 | 1.9 |
| K       | 6.0 - 3.8 Dec | 2.2 | 10 | 5.0 | 3.3 | 1.7 |
| L       | 4.3 - 3.0 Dec | 1.3 | 10 | 3.5 | 2.4 | 1.1 |

**Characteristics between visual axis and pupil diameter during robot-assisted eating**

Fig. 3 shows that the visual axis is placed among the plate, the spoon, and the food from task start to the end of P2. First, the visual axis moved to the food early in P1. Next, the visual axis on the plate was equivalent to the position at which the spoon of My Spoon arrived. Finally, the visual axis shuttled back and forth among the plate, the spoon, and the food in P1. Although the visual axis moved to the plate from a distant place from the spoon of My Spoon, the pupil diameter increased slowly. In early P2, the order of the visual axis position...
on the spoon, the food and the plate was transitory. Results suggest that the visual axis of the subjects serve the role of monitoring during eating motions in robot-assisted eating. These findings suggest that the visual axis is used for adjustment between the spoon and the food position.

Finally, the visual axis moved to the food, and the subject gave an order to lift the food using the joystick. During P2, the distance from the left eye to the plate did not change, but the pupil diameter increased gradually from P1 to P2 for reasons that remain unclear. In P3, the visual axis is placed only on the spoon. The pupil diameter decreased 1.7 mm, from 4.5 mm to 2.8 mm using My Spoon. The visual axis position between the spoon tip of My Spoon and the subject was nearer than the CVP of unassisted eating. Furthermore, the difference of the pupil diameter in robot-assisted eating was greater than that for unassisted eating. Therefore, the pupil diameter in robot-assisted eating was less than that during unassisted eating. The minimum pupil diameter in robot-assisted eating resembles that of the near reflex. These data show that the subject looked carefully at the food and/or the spoon using accommodation convergence reflexes. The transitions of the visual axis and the pupil diameter were clear in all subjects. Results show that the visual axis approached the spoon from the plate to near the mouth. Using My Spoon, all subjects showed a similar transition of the visual axis and the pupil diameter. When the subjects have no somatosensory information, they depend only on visual information. Therefore, robot-assisted eating must identify the distance to the spoon from the mouth using visual information.

**Differences between unassisted eating and robot-assisted eating**

As described above, the visual axis showed a difference between unassisted eating and robot-assisted eating. The maximum difference was the presence of CVP. In unassisted eating, CVP is present, and the visual axis is located on the food or the spoon from P3 start to CVP. However, robot-assisted eating has no CVP. The visual axis is located on the food or the spoon from start until the end of the eating motion in P3. A recent report described similar results of the visual axis in caregiver-assisted eating (Saitou, 2006). In addition, unassisted eating showed numerous types of pupil diameter changes in 7 out of 12 subjects. Conversely, robot-assisted eating showed a pupil diameter decrease in all subjects. Even if the visual axis is applied to the food, the pupil diameter changes differ. Unassisted eating has a visual axis that did not monitor the food. However, it has been suggested that the pupil diameter decreases to the same degree as the near reflex when the visual axis shows careful monitoring of the food. During robot-assisted eating the distance between the spoon and the subject mouth must be measured visually. In robot-assisted eating, somatosensory information is not obtained. Therefore, anxiety occurs among all subjects when the spoon tip nears the subject.

These findings show that unassisted eating and robot-assisted eating elicit different physiological responses in healthy subjects.

**Practical application of occupational therapy**

In this study, unassisted eating and robot-assisted eating showed clear differences in physiological responses. Because of influences such as head injury and spinal cord injury, a challenged person might use a meal support robot. In robot-assisted eating, characteristics of physiological responses are important. However, voluntary eating with voluntary timing of the subject is necessary to improve QOL. OTRs must teach subjects to use meal support robots for QOL improvement. Therefore, it is necessary for OTRs to understand motion guidance methods and characteristics of physiological response using assistive technology.

**Study limitations**

Findings of this study demonstrated that unassisted eating and robot-assisted eating elicit different physiological responses in healthy subjects. Nevertheless, no comparison was made with challenged persons during unassisted eating or robot-assisted eating. In the future, the authors would like to investigate unassisted eating and robot-assisted eating with challenged persons.

**Acknowledgments:** The authors thank Prof. Takuro Hatakeyama, Dr. Sumio Ishii, Prof. Kunihiko Maeda and Prof. Toshiaki Sato for their valuable suggestions related to this study.

We also thank Ms Chihiro Sato OTR, Ayumi Minegishi OTR and students of Yamagata Prefectural University of Health Sciences for their excellent assistance. This work was partly supported by grants from the Yamagata Health Support Foundation.

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