Introduction

Many reports have described analysis of eating, which is important for independence of self-care [1, 2, 3, 4, 5]. Previous our report has described characteristics of healthy participants’ visual axis and pupil diameter found during unassisted eating and robot-assisted eating [6]. Results show that all participants have a critical visual point (CVP) during unassisted eating as the spoon moves from the plate to the mouth. The CVP contributes to eye-hand coordination during eating, facilitating monitoring of smooth upper extremity motion and spoon manipulation. The CVP is the final point during the eating motion [7]. However, the CVP disappeared in all participants during robot-assisted eating. These findings suggested that the subjects followed the food with their eyes until just before it entered their mouths during robot-assisted eating. The Japanese geriatric health service facilities and at home needed caregiver-assisted eating in the subjects. Characteristics of the visual axis and pupil diameter during caregiver-assisted eating remain unclear. In other words, from the characteristics among unassisted eating, robot-assisted eating, and caregiver-assisted eating, we can find a theoretical basis for occupational therapists to provide caregivers with appropriate care guidance methods for their subjects. Therefore, this study examined the kinetics of the visual axis and pupil diameter during caregiver-assisted eating.
Methods

Participants

Twelve healthy volunteers (5 men, 7 women) participated in the study. The age range was 20–26 years (mean age, 22 ± two years). All participants had vision sufficient to obtain a driver’s license, with no color vision abnormality. They had affiliated psychic function and did not have diseases or injuries that would impair daily living activities. All participants provided informed consent to undergo the experimental procedures, which were approved by the Ethics Review Board of the Yamagata Prefectural University of Health Sciences (1210-09), Yamagata, Japan.

Instrumentation and data acquisition

Data were collected with a sampling frequency of 30 Hz using an eye tracker (EMR-8B; NAC Image Technology Inc., Tokyo, Japan), which detects infrared reflections from the cornea, and a digital video camera (30 frames per second, NV-GS320; Panasonic Inc., Osaka, Japan). The digital video camera, located to the side of the participant, recorded motion of the spoon bowl from the plate to the mouth. A digital motion picture waveform real-time synchronous recording system (the Teraview; Gigatex Co. Ltd., Osaki, Japan) was synchronized with a field image, a pupil image, and a video camera image.

Procedures

Experimental conditions

Brightness in the test room was fixed at 652 lux. The room temperature was set to about 24°C. Each participant sat on a chair (400–450 mm tall). The participant held the eating assistant’s spoon before the trial began. The distance between the mouth and the plate during caregiver-assisted eating was fixed as 338–471 mm for all participants. The experimental food was a cereal with 15-mm-diameter toroidal pieces (Kokokun-no-chocowa; Kellogg Co., Tokyo, Japan). The participant’s eyes were covered with a visual mask to prevent prior visual information. The mask was removed at the start of the eating task. The trial ended when the food was in the participant’s mouth. The eating task was caregiver-assisted eating (10 trials).

First, the participant was asked to eat food just as in daily life. Therefore, we did not force the subjects to look at the food or the spoon except to say, “Please eat as usual”. A caregiver observed the motion speed, spoon bowl trajectory, and eating motion accuracy. The caregiver-assisted eating of participants was observed similarly to unassisted eating.

Data analysis

1. Motion phases

Eating task motions were divided into three phases using video data: phase 1 (P1), the motion of moving the spoon to reach the food; phase 2 (P2), the motion of picking up the food; and phase 3 (P3), the motion of moving the spoon to the participant’s mouth. P3 was also defined as the “eating motion.”

2. Classification of eye movement

The visual axis position was ascertained from a picture using a field camera, and was pursued during the eating task. Eye movements were classified as saccadic eye movement (SEM), smooth pursuit eye movement (SPEM), fixation, and others. SEM was defined as eye movement of angle speed greater than 50°/s. SPEM was defined as eye movement of angle speed <50°/s. Fixation was defined as eye movement inactivity that continued longer than 0.10 s. Fixation was judged to have occurred when the eye mark stopped at the same position for more than three field camera images under these conditions.

3. Visual axis position and spoon bowl motion

The visual axis position was divided into four categories: The plate showed a block with the food. The spoon showed the visual axis position on the spoon bowl without the food. The food showed the visual axis position on the food. Other positions showed blinking or no placement of the plate, spoon bowl, or food. The CVP was defined as the spoon bowl 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, Japan). The pupil diameter of each participant, which was measured before and after the near-reflex test, was used as the reference to assess differences between before and after the near reflex test. Three patterns of pupil diameter change in P3 were assessed: increase, decrease, or no change. All trials included every pattern. The quantity of change of the pupil diameter was calculated based on the difference of the maximum and the minimum (min-to-max or max-to-min) of P3.

Results

Figure 1 (participant A) presents changes in the
visual axis and pupil diameter that occurred during caregiver-assisted eating. The spoon reached the food within 1.3 s from the trial start (end of P1). The visual axis of the participant was on the food. Furthermore, the participant picked up the food with the spoon in 1.9 s (end of P2). During P2, the visual axis position changed from the food, to the spoon, to the food. Next, the participant moved the spoon to the mouth. It reached the mouth in 3.9 s from the trial start (end of P3). During P3, the visual axis position changed from the food to the other 1.3 s after the trial start. The spoon at this time was located 91 mm from the left eye of the participant. No CVP was identified during P3.

Although the order of the visual axis position varied among trials, the visual axis position and the eye movement pattern were similar from P1 to P3. Additionally, all participants showed the same visual axis positions and eye movement patterns as this participant.

In P1, the visual axis was fixed on the food 0.1 s from the trial start. The eye movement pattern changed from SEM (for 0.1 s), to fixation (for 0.2 s), to other patterns (for 0.2 s), to fixation (for 0.8 s). At that moment, the pupil diameter increased by 0.6 mm, from 2.7 mm to 3.3 mm. During P2, the eye movement pattern changed from fixation (for 0.2 s duration), to SPEM (for 0.1 s), to fixation (for 0.3 s), to SEM (for 0.1 s). The pupil diameter increased by 0.3 mm, from 3.3 mm to 3.6 mm. During P3, the eye movement pattern changed from fixation (for 0.2 s duration), to SPEM (for 1.0 s), to fixation (for 0.4 s), to other patterns (for 0.3 s). The pupil diameter decreased by 0.4 mm, from 3.8 mm to 3.4 mm. In the participant, the pupil diameter showed
similar changes to those of other trials. However, this participant’s change in pupil diameter showed only a decrease in P3 (Table 1).

Among all participants, the CVP disappeared completely in all trials during P3.

The min-to-max and max-to-min pupil diameters, differences, and changing counts for caregiver-assisted eating in all participants during P3 are shown in Table 1.

For participant A, the max-to-min pupil diameters decreased from 3.7 to 3.4 mm. The difference in pupil diameter was 0.3 mm. The pupil diameter decreased in all trials. Eight participants showed decreased pupil diameter.

For participant K, the min-to-max and max-to-min pupil diameters increased (from 5.0 to 5.3 mm), decreased (from 4.9 to 4.8 mm), or showed no change (stable at 5.4 mm). The pupil diameter increased by 0.3 mm and decreased by 0.1 mm. The pupil diameter change counts respectively showed an increase, decrease, and no change in 6, 2, and 2 trials. The near reflex value decreased by 1.2 mm, from 4.4 mm to 3.2 mm. Three participants showed an increase, a decrease,
and no change in pupil diameter.

In participant L, the min-to-max and max-to-min pupil diameters respectively increased (from 3.4 to 3.6 mm) and decreased (from 3.6 to 3.4 mm). The pupil diameter increased by 0.2 mm and decreased by 0.2 mm. The pupil diameter change counts increased by 2 and decreased by 8 only in participant L. The near reflex value decreased by 0.5 mm: from 3.2 mm to 2.7 mm.

Discussion

All participants had visual axis on a spoon or food from P1 to P3 in caregiver-assisted eating. Moreover, CVP disappeared completely in all trials during P3 of all participants. The result was similar to a previous report [8]. CVP contributed to the role of eye-hand coordination during eating, as shown by visual monitoring of smooth upper extremity motion and spoon manipulation [7]. CVP is the final spot [7, 9]. We speculated that the participant sub-consciously or consciously moves without dropping food from the spoon at CVP during unassisted eating [7]. Previous reports have described that no CVP exists for robot-assisted eating [6]. Therefore, caregiver-assisted eating is natural in non CVP. A participant does not have somatosensory information during eating motion in caregiver-assisted eating. The positional information of a spoon is obtained only from visual information [6]. We speculated that participant anxiety was stronger with caregiver-assisted eating than with unassisted eating. All participants feel anxious when the spoon tip nears the participant.

Table 1 shows pupil diameter P3 of three patterns. Most patterns showed only about 67% decrease of pupil diameter. These findings were similar to results obtained for robot-assisted eating [6]. The pupil diameter decrease occurs in the near reflex. These data suggest that the participant looked carefully at the food or the spoon using an accommodation reflex and a convergence reflex [10]. The next pattern was a 25% increase, a decrease, and no change of pupil diameter. One other participant showed an increase and a decrease of pupil diameter. Participants C and L of different types of pupil diameter change showed that the decrease ratio of pupil diameter was frequent. Participants D and K showed that the increased ratio of pupil diameter was frequent. As described above, these findings suggest that a decrease of pupil diameter occurs in the near reflex. In unassisted eating, there was no obvious decrease in pupil diameter as in the near reflex, and the pupil diameter was sometimes increased [6]. We speculated that the timing, speed, and trajectory of eating motion in caregiver-assisted eating resembled those found for unassisted eating. However, the causes of an increase and lack of change in pupil diameter remain unclear.

This study revealed that caregiver-assisted eating resembled kinetics of visual axis and pupil diameter during robot-assisted eating. Eating in natural timing, natural speed, and natural trajectory improves the participant’s eating motivation. Therefore, a caregiver must match the timing, speed, and trajectory of eating motion with those of an individual participant. For further quality of life improvement, the occupational therapist (OTR) must lead unassisted eating by the participant. The OTR, who understands biological responses during eating motion, must teach a caregiver assistance methods that are suitable for a participant.

Study limitations

Caregiver-assisted eating elicited physiological responses in healthy participants. However, challenged persons were not assessed during caregiver-assisted eating. Further studies are under consideration to investigate caregiver-assisted eating in challenged persons.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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