

Construction of Quantitative Assessment Index for Infant-holding Postures During Bottle-feeding

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Abstract—An effective bottle-feeding method for infants with cleft lip and/or palate (CLP) is the Kumagai method. However, the number of specialists in the method is limited and providing direct instruction to many people is challenging. To solve this problem, developing a guidance system that enables learners to acquire Kumagai method skills without a direct instructor is desirable. Constructing such a guidance system requires defining a quantitative assessment index for skills in the Kumagai method. Therefore, in this study, we propose a new quantitative assessment index for infant-holding posture, which is the most basic and crucial skill in this method. Our experiments confirmed that the proposed index could stably assess the reproducibility of the infant-holding posture in the Kumagai method while reducing the effect of postural fluctuations during the feeding motion.

I. INTRODUCTION

Cleft lip and/or palate (CLP) is a congenital anomaly that affects 9.92 per 10,000 people worldwide [1]. Infants with CLP have difficulty creating negative pressure in the oral cavity during bottle-feeding, which leads to feeding difficulties [2], [3]. An effective bottle-feeding method for such infants is the Kumagai method [4].

This method allows infants with CLP to create the negative pressure needed to drink milk. It is preferable to receive direct instructions from specialists to master the Kumagai method. However, the number of specialists in the method is limited, and providing direct instruction to many people is difficult. To solve this problem, it is desirable to develop a guidance system that allows learners of the Kumagai method to acquire its skills without direct instruction from instructors, relying solely on a simplified system, such as image-based posture estimation via a smartphone.

To construct a guidance system, it is necessary to define a quantitative assessment index for the three critical skills in the Kumagai method: 1) infant-holding postures, 2) bottle-holding techniques, and 3) bottle movements. Of these, the infant-holding posture is the most basic and important. Therefore, in this study, we focus on defining a quantitative assessment index for the infant-holding posture used in the guidance system. In the Kumagai method, caregivers are required to hold the infant straight in a slightly upright

position. Here, in the image-based posture estimation, the infant is often obscured by the caregiver's arms, making the detection of the infant's posture challenging. Therefore, this study aims to develop an assessment index that enables the evaluation of the infant-holding posture based solely on the caregiver's posture.

A yoga posture guidance system is a conventional system that quantitatively assesses a user's current posture based on likelihoods calculated from joint angle distributions and guides the user toward an appropriate posture without the need for an instructor. [5]. However, the yoga posture guidance system cannot be applied directly to the infant-holding posture during bottle-feeding for two reasons. First, unlike yoga poses in which the entire body is used to achieve a particular posture, the infant-holding posture is performed using only one part of the body. Furthermore, in the infant-holding posture, it is necessary to assess more subtle differences in posture compared to the yoga posture. Therefore, the infant-holding posture requires a more detailed evaluation of specific joint angles. When the conventional system is used directly, joints with low relevance to the target posture prevent proper posture assessment. Second, while yoga postures are static, the holding posture of a caregiver during bottle-feeding can change slightly, for example, the motion of inserting the bottle into the infant's mouth. This slight change results in the calculation of likelihoods that differ significantly from time to time, making stable posture assessment during bottle-feeding difficult.

To solve these problems, based on the conventional system, we propose a new quantitative assessment index for the infant-holding posture during bottle-feeding. Unlike the conventional system, the proposed index calculates the likelihood using only the joint angles related to the infant-holding posture. Furthermore, for particularly important joints, the angles are decomposed into their directional components, and the likelihood is calculated for each component. The new index also calculates the likelihood from multiple frames during bottle-feeding to achieve a stable posture assessment independent of slight posture changes, whereas the conventional system calculates the likelihood from one frame.

II. RELATED WORK

Ueki et al. [4] conducted a study on the Kumagai method, a bottle-feeding technique that uses a long nipple bottle. Their findings qualitatively revealed the detailed techniques involved in the Kumagai method. However, the quantitative characteristics of the Kumagai method remain unexplored.

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On the other hand, there are various methods for quantitatively assessing postures during specific motions [5], [6], [7]. Martinez et al. [6] proposed a quantitative index to assess postures during lifting and lowering tasks using joint angles. Fernandez et al. [7] proposed a system that automatically calculates a traditional assessment index of physical fatigue from RGB images. However, these methods focus on the assessment of these postures and do not consider guiding users towards adopting an appropriate posture based on the assessment results.

A method that considers both assessment and guidance is the system proposed by Dittakavi et al [5], which identifies and assesses different types of yoga postures and provides guidance on how to achieve an appropriate posture. By using histograms of joint angles for posture assessment, their system can automatically detect joints at inappropriate angles from RGB images. However, this system is designed for the assessment of static postures such as yoga postures. When applied to the infant-holding posture during bottle-feeding, it is influenced by postural fluctuations caused by the feeding motions, making it difficult to achieve a stable assessment of the infant-holding posture.

III. PROPOSED METHOD

In this study, we first measure the posture of a caregiver performing the Kumagai method and generate reference histograms of the joint angles during part of the feeding motion applied to an infant doll with CLP. Subsequently, for each joint of a participant, we calculate the likelihood as an assessment index using the participant's joint angles and the reference histogram of the joint.

In this section, first, we describe the baseline of our method. Subsequently, we detail the measurement of infant-holding postures and the assessment index for each joint calculated from the measured postures.

A. Baseline

Our method is based on the conventional assessment index used in the yoga guidance system [5]. In the index, first, a reference histogram is generated to quantitatively define the appropriate yoga posture for each joint by collecting the joint angles estimated from the images of the appropriate postures. Then, for an image of the learner's yoga posture, the likelihood of each joint is calculated using a reference histogram. The likelihood is higher if the learner's joint angle is appropriate. In the conventional method, a skeleton is estimated from posture images using a pose estimation network, and the joint angles of ten major body joints are calculated as assessment targets. The number of bins in the reference histogram is set to 10.

Next, the likelihood of each joint for the learner is calculated based on the created reference histogram. Similarly, skeleton and joint angles are extracted from the learner's images using a pose-estimation network. To quantitatively assess the match between the appropriate posture and the learner's posture, for each of ten joints of the learner, the

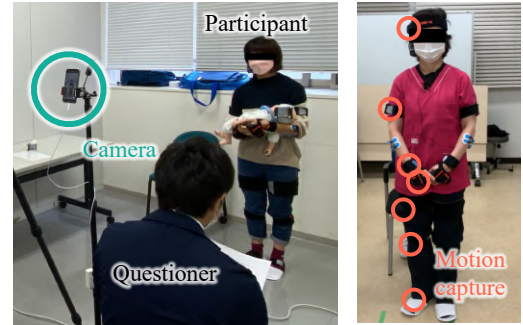


Fig. 1: Measurement setup

likelihood L_p is calculated as follows:

$$L_p(j) = \frac{\exp(t_{p,j})}{\sum_{i=1}^{10} \exp(t_{p,i})}, \quad (1)$$

where $t_{p,i}$ denotes the frequency of the i -th bin in the reference histogram of a joint p and j denotes the bin of the reference histogram where the learner's joint angle belongs.

B. Measurement of Infant-Holding Postures

For each caregiver, we measured the full-body posture of the caregiver using a motion capture system to obtain the joint angles of the caregiver when performing the Kumagai method appropriately and when not. This section first explains the participants as caregivers and the measurement procedure and then describes the measurement environment. Finally, we explain how to extract a part of the feeding motion to be assessed in this study and calculate the joint angles from the extracted motion.

1) *Measurement Environment*: A camera was positioned in front of the participants to capture their postures (left in Figure 1). Additionally, a microphone was attached to the participant's chest to record the conversation between the interviewer and the participant during the measurement.

Next, as shown on the right side of Figure 1, the full-body postures of the participants were measured using a wearable motion capture system based on inertial sensors (MVN Xsens Awinda, Movella Holdings, Inc.). Wearable motion capture allows for full-body posture measurements, even if parts of the participant's body are obscured by an infant.

The long nipple bottle (Pigeon Co.), as shown in Figure 2(a), was used as a feeding bottle. Furthermore, a baby doll (MC-003, Medical Craft and Prosthetics Co., Ltd.), as shown in Figure 2(b), was used to simulate an infant with CLP. The doll was designed to represent a newborn with a height of approximately 50 cm, weight of approximately 2,800 g, and head circumference of approximately 31 cm. To simulate CLP, parts of the lip and palate were cut out, as shown in Figure 2(b).

2) *Participants and measurement procedure*: Five nurses mastering the Kumagai method participated in the measurement. These nurses worked in a university-affiliated dental hospital that provided treatment to many infants with CLP. The choice of the arm holding the doll was left to each

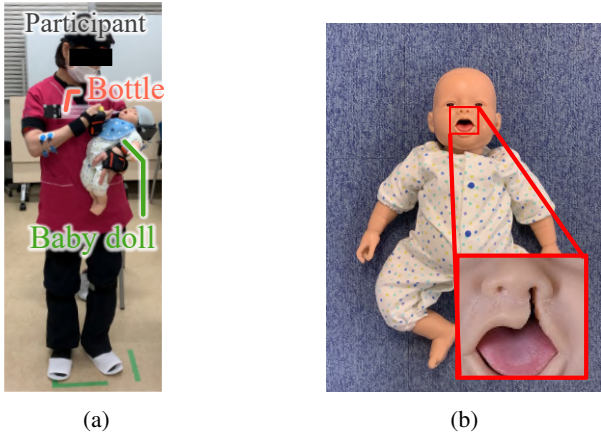


Fig. 2: (a) A participant holding the doll and (b) a baby doll with CLP.

participant: four chose their left arm, and one chose her right arm. The posture of the latter was reversed left and right before assessment.

During the measurement, the participants first bottle-fed the infant doll using the Kumagai method as an appropriate posture shown as Figure 2(a). They were then bottle-fed again in an inappropriate posture, which is often adopted by those who have not yet mastered the Kumagai method.

3) Motion extraction and calculation of joint angles:

The feeding action in the Kumagai method can be divided into multiple segments based on the caregiver's movements, such as the insertion and removal of the bottle nipple. This study focuses on the initial segment, in which the caregiver brings the bottle close to the infant's mouth, using it as assessment data. The assessment data were extracted from the video recorded by the camera during the measurements. The lengths of the extracted data ranged from a minimum of 37 frames to a maximum of 380 frames at 30 fps.

This study focused on seven joints primarily related to the upper left side of the body, which are strongly associated with holding an infant, and calculated their angles. Of the 22 joint coordinates that could be obtained from the wearable motion capture, 10 joints were used to calculate the joint angles. The details of the seven joints are listed in Table I, and the joint angles depicted in the skeletal model are shown in Figure 3.

4) *Ethical Considerations:* All participants were informed that their names and images would not be identifiable by third parties throughout the study, that participation was voluntary, that refusal would not result in any disadvantage, and that the purpose and content of the study would be explained in advance. Consent was obtained both orally and in writing. The Institutional Ethics Review Committee of Kyushu University approved this study (code, 22136-02; September 26, 2022).

C. Assessment Index for Each Joint

Similar to the conventional method, our method generates a reference histogram for each joint and calculates the

likelihood as an assessment index for the joint based on the reference histogram. However, in contrast to the conventional method, which focuses on the static yoga posture, the present study focused on the infant-holding posture with minute postural fluctuations during the feeding motion. To achieve a stable posture assessment while reducing the influence of such fluctuations, we proposed a new likelihood calculated from sequential multiple frames based on the conventional likelihood calculated from a single frame. Additionally, unlike yoga poses, in which joint angle variations are large, the posture of holding an infant involves small joint angle changes. Therefore, we calculated the class interval and class boundaries based on the distribution of joint angles in all appropriate postures to generate a reference histogram reflecting the distribution of joint angles in the infant-holding posture. After describing the method of creating a reference histogram from the measured joint angles, we describe the calculation of the likelihood for each joint.

1) *Generation of the Reference Histogram:* A reference histogram for each joint is generated using the joint angles calculated from the appropriate postures of the five participants, as described in Section III-B.3. First, a temporal histogram is generated using the joint angles of the five appropriate postures. In the temporal histogram, the lower limit of the smallest bin, the upper limit of the largest bin, and the number of bins are denoted as l , r , and n , respectively. The number of bins n is set to 10, which is consistent with the conventional method. The values of l and r are determined by exploring the entire range that satisfied $\{0 \leq l < r \leq 180\}$ to maximize the average likelihood calculated from the five appropriate postures.

Next, the temporal histogram is normalized such that the sum of the frequencies is equal to 1. Then, considering the possibility that the joint angles of the assessed posture might fall outside the range of the generated 10 bins, two additional bins are added for angles smaller than l and larger than r , resulting in a total of 12 bins ($n = 12$). This histogram is defined as the reference histogram.

2) *Calculation of Likelihood:* For each joint of a participant, the likelihood is calculated based on the reference histogram of the joint. The likelihood is greater than 0 and 1 or less, with values closer to 1 indicating a more appropriate posture. First, for each of seven joints of a participant, a histogram $S_{p,f}$ comprising n bins is generated from consecutive f -frames as the participant's histogram. The class interval and boundaries of the histogram are the same as those of the reference histogram. Next, using the reference histogram and the participant's histogram, the likelihood λ_p for a joint p of the participant is calculated as the assessment index in the proposed method:

$$\lambda_p(S_{p,f}) = \frac{e+n-1}{ef \sum_{i=1}^n \exp(t_{p,i})} \sum_{j=1}^n s_{p,j} \exp(t_{p,j}), \quad (2)$$

where $S_{p,f} = \{s_{p,k} | k = 1, 2, \dots, n\}$ is the set of frequencies of each bin of the participant's histogram and the sum of all frequencies equals the number of frames f . Additionally, $t_{p,i}$ and $s_{p,i}$ are the frequencies of i -th bin in the reference

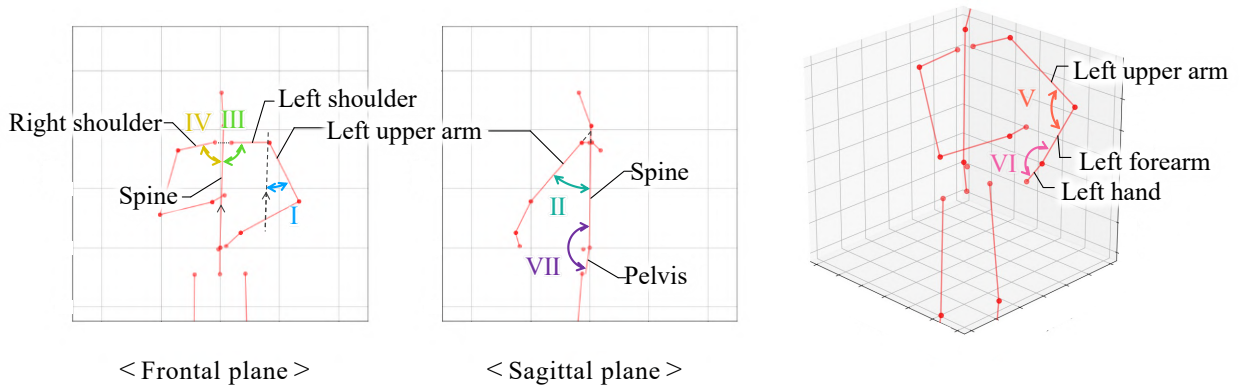


Fig. 3: Joint angles used for the assessment. The joint angle numbers are the same as in Table I.

TABLE I: Joint angles used for the assessment

Joint Name	Description
1. Left shoulder (abduction)	Between the spine and the left upper arm in the frontal plane
2. Left shoulder (flexion)	Between the spine and the left upper arm in the sagittal plane
3. Left sternoclavicular	Between the spine and the left shoulder
4. Right sternoclavicular	Between the spine and the right shoulder
5. Left elbow	Between the left upper arm and the left forearm
6. Left wrist	Between the left forearm and the left hand
7. Spine	Between the spine and the pelvis

histogram and participant's histogram of joint p , respectively. Then, n is the number of bins and is set to 12 in this study. In addition, e refers to the base of the natural logarithm.

IV. EXPERIMENTS AND DISCUSSION

To verify the effectiveness of the proposed method, we compared the likelihoods calculated using the conventional method [5] with those calculated using the proposed method. In addition, to validate the proposed method, we compared the likelihood of each participant's appropriate posture, which satisfied the requirements of the Kumagai method, with those of inappropriate postures that did not satisfy them. The details of these postures are described in Section III-B.2.

A. Comparison with the Conventional Method

In the conventional method [5], a single likelihood is calculated using a one-frame posture. In contrast, in the proposed method, a single likelihood is calculated from multiple-frame postures during the initial segment. Therefore, for the conventional method, we calculated the likelihood of each posture in each frame during this segment. The frame-varying likelihood obtained using the conventional method was compared with that obtained using the proposed method. Figure 4 illustrates the results for the participant with the largest difference in likelihood as an example.

As shown in Figure 4, the likelihood of the conventional method changed significantly during the initial segment, and the assessment results varied depending on the frame. However, the likelihood of the proposed method was the average of the frame-varying likelihoods obtained using

the conventional method, and the assessment result was consistent during the segment. These results show that the proposed method can assess the holding posture during the initial segment more stably than the conventional method while reducing the effects of postural fluctuations. Such stable evaluations will enable caregivers to improve their posture smoothly without confusion.

B. Comparison of Likelihoods Between Appropriate and Inappropriate Infant-Holding Postures

Figure 5 shows appropriate and inappropriate postures of the participant (No. 1), and Figure 6 shows these postures represented using blue and red skeleton models, respectively. Furthermore, Figure 7 shows the likelihoods calculated from the appropriate and inappropriate postures when holding the infant doll. In this figure, the likelihoods of all seven joints for each posture of a participant are calculated, sorted in descending order, and displayed in a radar chart. Therefore, the area of the radar chart was proportional to the overall posture assessment score. Table II lists the areas of the radar charts for each posture for all participants. A paired t-test between the areas of appropriate and inappropriate postures for all participants revealed a significant difference at the 5% significance level. These results demonstrate that the proposed method can be used to quantitatively assess the differences between appropriate and inappropriate infant-holding postures. The reversal of the result for participant No. 4 suggests that it is necessary to assign relative importance to the seven joints used in this analysis and apply appropriate weighting during the evaluation.

In Figure 7, the left sternoclavicular joint shown as III had an average decrease in the likelihood of 0.09 ± 0.15 in the inappropriate postures compared with the appropriate postures. In contrast, the likelihood of the spine in an inappropriate posture, shown as VII in Figure 7, decreased by only 0.01 ± 0.02 from appropriate postures. Thus, in the spine, the difference in the likelihood between the appropriate and inappropriate postures was smaller than that in the other joints. This is because, in the left sternoclavicular, the inappropriate postures show greater angle variation

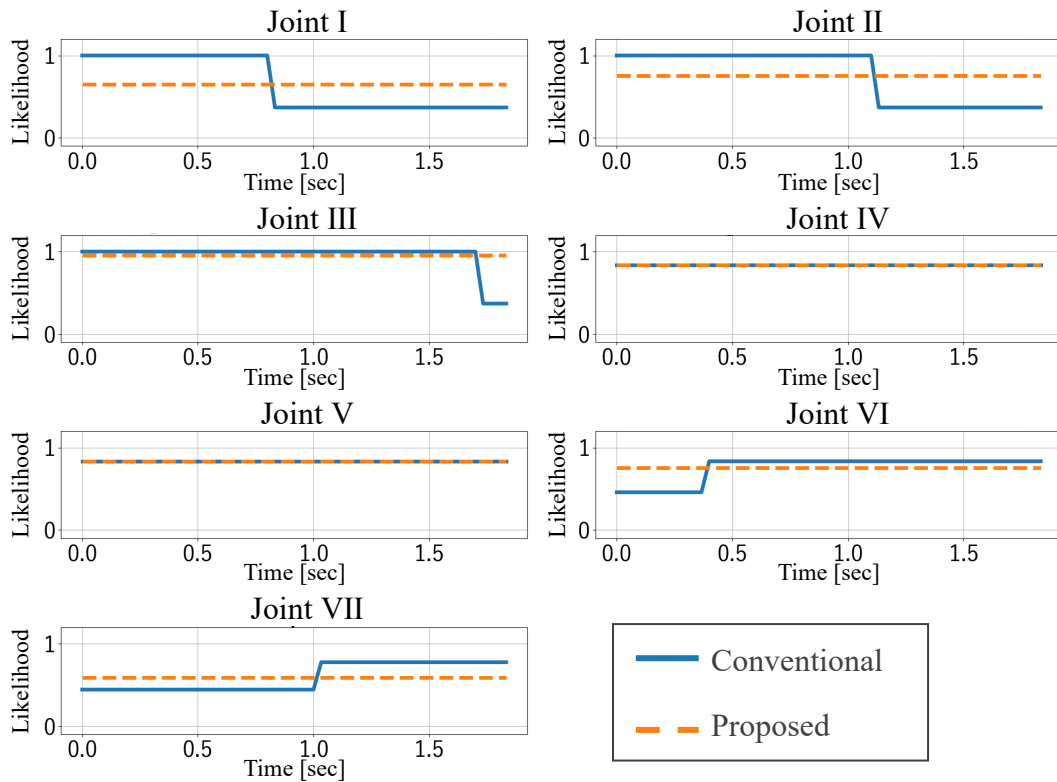


Fig. 4: Likelihoods of the participant (No. 1) calculated from the proposed method (orange dotted line) and the conventional method (blue line)

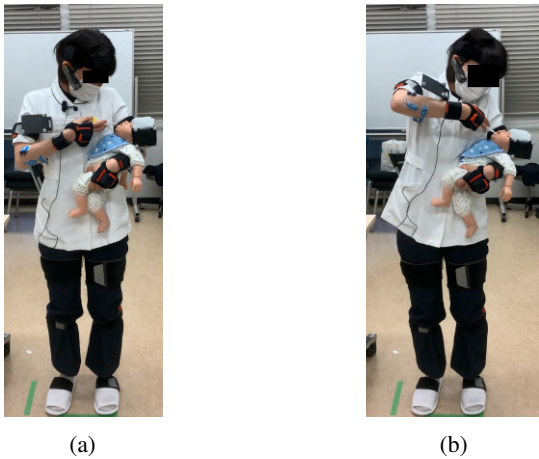


Fig. 5: (a) Appropriate and (b) inappropriate postures of the participant (No. 1).

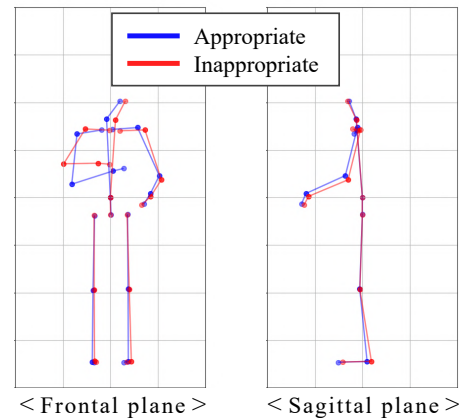


Fig. 6: Appropriate (blue) and inappropriate (red) postures of the participant (No. 1) represented using skeleton models.

than appropriate postures (Figure 8(a)), whereas the angle distribution in the spine is similar for both postures (Figure 8(b)).

However, the inappropriate postures in this study were simulated by specialists of the Kumagai method, and it is possible that the spinal angles may also vary in actual non-learners of the method. Therefore, the proposed index must be validated using a wider variety of postures from actual

non-learners.

V. CONCLUSION

In this study, we proposed a new quantitative assessment index to stably assess the infant-holding posture in the Kumagai method using the joint angles of a caregiver. The experimental results show that the proposed index can reduce the effect of postural fluctuations and assess the infant-holding posture during the feeding motion more stably than the conventional index. Moreover, we confirmed that

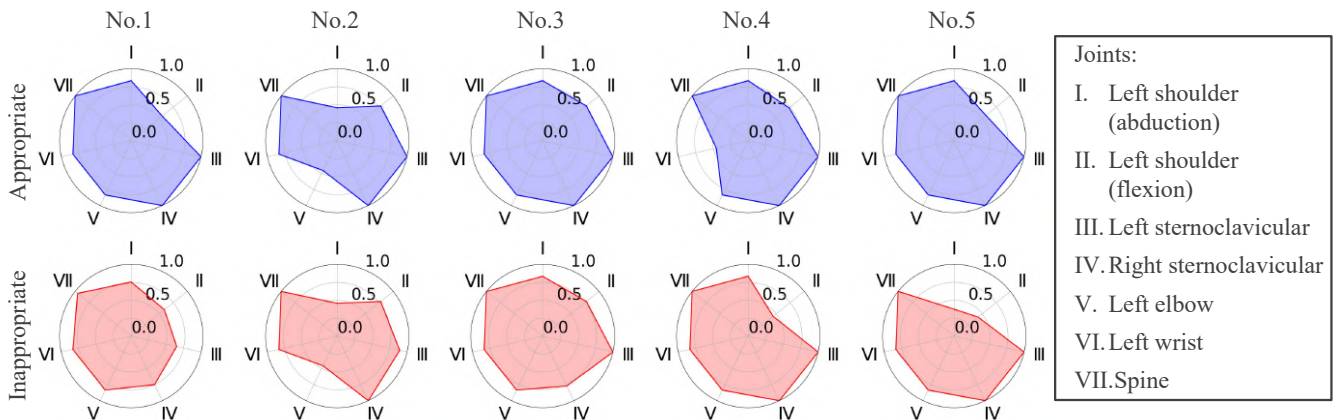


Fig. 7: Likelihoods of joints in appropriate and inappropriate infant-holding postures for all participants

TABLE II: The area of the radar charts representing the likelihoods for appropriate and inappropriate postures

Participant	Appropriate	Inappropriate
No. 1	2.05	1.62
No. 2	1.76	1.69
No. 3	2.21	2.05
No. 4	1.93	1.97
No. 5	2.06	1.73
Average \pm Standard deviation	2.00 \pm 0.17	1.81 \pm 0.19
<i>p</i> -value		0.04*

*Significant difference ($p < 0.05$)

there were significant differences between the likelihoods obtained by applying the proposed index to appropriate and inappropriate infant-holding postures. This indicates that the proposed index can quantitatively assess the reproducibility of the infant-holding posture in the Kumagai method.

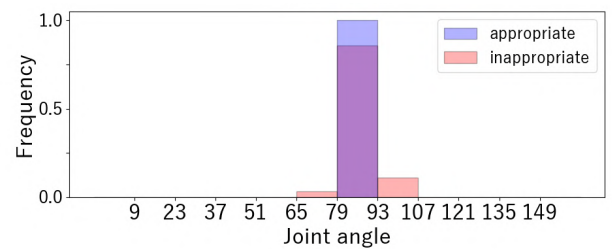
In the future, to confirm the availability of the proposed index, it will be applied to the infant-holding postures of individuals who have not mastered the Kumagai method. Then, we will verify whether the assessment results using the proposed index are consistent with those of specialists in the Kumagai method.

VI. ACKNOWLEDGMENT

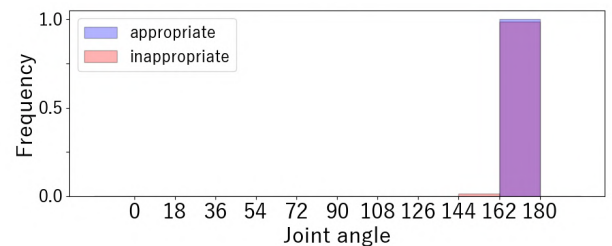
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(a) Left sternoclavicular



(b) Spine

Fig. 8: Histograms of joint angles calculated from all appropriate (blue) and inappropriate (red) postures with overlapping areas between the two shown in purple.

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