

## Infant's brain responses to live and televised action

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Whether human infants perceive televised stimuli in the same way to live stimuli largely remains unknown. Action observation, which has been extensively confirmed to elicit activation of internal motor representation, provides a promising framework for investigating this issue. This 'mirror-matching' property has been found in the monkey premotor cortex as well as the premotor and primary motor cortices in human adults. Although larger activation in observing a live action compared to a televised action in adult subjects has been reported, it is unknown whether the same neural response is obtained from human infants. To address this issue, we first measured the activity of motor areas in adult subjects while viewing either a live or televised action of other people by using near-infrared spectroscopy. The motor areas that were activated when the subject themselves performed an action were also activated during action observation in the live setting, while this was not evident in the TV setting. We then conducted qualitatively the same experiment with 6- to 7-month-old infants. The infant's motor areas were significantly activated when observing a live person performing an action. Although we also found activation in the same area during action observation in the TV setting, the difference in activity between action observation and object-motion observation was significant only in the live setting. Our results are the first to demonstrate activation in motor areas during action observation in human infants. We suggest that human brain responds differently to the real world and the virtual world.

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### Introduction

The influence of television on infants and young children has recently become a great concern. Although there is considerable debate about this issue (American Academy of Pediatrics, 1999; Johnson et al., 2002), the mechanism that processes stimuli from television is still poorly understood. One of the most important issues of television viewing is observational learning and imitation. Longitudinal correlation studies (Johnson et al., 2002) and experimental behavioral studies (Bandura et al., 1963; Barr and

Hayne, 1999; Meltzoff, 1988) have addressed this problem, and some have suggested that information obtained through television can influence the child's short- and long-term behavior after viewing. For example, a classical experiment by Bandura demonstrated that the occurrence of aggressive behavior in children was increased after viewing the model's violence on television (Bandura et al., 1963). Since there is substantial evidence that infants imitate various kinds of live body movement, including hand gestures of others in 6-month-old infants (Piaget, 1951; Meltzoff and Prinz, 2002; Learmonth et al., 2004), it is possible that infants can imitate the model presented on television as well. However, this problem has not yet been fully investigated. One developmental study reported that infants imitated a televised action of a model (Meltzoff, 1988), while another claimed that infants imitated actions presented on television less frequently than those modeled live (Barr and Hayne, 1999). In addition, the previous studies have not directly addressed the problem of what exactly is occurring in the infant brain *during* viewing television, which is important for the complete understanding of the influence of television on infants.

Recent neurophysiological and functional neuroimaging studies have extensively demonstrated that action observation activates the observer's internal motor representation of the same action. This 'mirror-matching' property was first found in the monkey premotor cortex and then in human adult premotor and primary motor cortices (M1) (Fadiga et al., 1995; Hari et al., 1998; Iacoboni et al., 1999; Nishitani and Hari, 2000; Rizzolatti et al., 2001) and is considered to be relevant not only to imitation, but also to action understanding, empathy, theory of mind, and intersubjectivity (Gallese, 2003). Recently, a magnetoencephalography (MEG) study with human adult subjects investigated differences in neural responses to live and televised actions (Jarvelainen et al., 2001). In their experiments, the subject's median nerves were stimulated during action observation. They found a significant suppression of post-stimulus rebound of 15- to 25-Hz activity in the primary motor area when compared to the rest condition, and the amplitude of suppression was greater in the live condition than in the TV condition. This result implies that live and televised actions are differently processed in the observer's brain. However, this hypothesis should be examined more intensively, and to the best of our knowledge, no study has investigated the hemodynamic responses of the brain during observation of a live and televised

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action of other person. Moreover, it is unknown whether the same neural responses are obtained from infants observing live and televised action, due to the difficulty in applying neuroimaging methods to infants.

The purpose of this study was to investigate whether the infant's brain responds differently to a live or televised action by using a near-infrared spectroscopy (NIRS) apparatus. We also aimed to examine whether neural responses were different between adults and infants, as well as between action observation and object–motion observation. NIRS is a recently developed noninvasive neuroimaging technique, which is currently the only feasible method for measuring hemodynamic responses in awake infants under naturalistic settings, and its validity has been substantially confirmed (Baird et al., 2002; Miyai et al., 2001; Pena et al., 2003; Taga et al., 2003). To address this issue, we first conducted an experiment with adult subjects to determine whether there is greater activity in motor areas to a live action than to a televised action, as had been observed in a previous study (Jarvelainen et al., 2001), and can also be measured with NIRS (Experiment 1). Since the experimental design used in this previous study (Jarvelainen et al., 2001) appeared to be too simplified (the action observation conditions were compared to the 'rest' condition), we substantially modified the experimental design. In our experiment, the subject watched an action of a model (action observation condition) in succession to a moving object under physical laws, in order to confirm that measured brain activity reflects observation of an action and not that of a general moving object. Further, in another condition, the subject was presented with an object manipulated by an invisible model (no body parts of the model were visible; object–motion observation condition) in succession to the moving object, in order to see whether observing intentional manipulation (or animate movement) of an object alone is sufficient to activate motor areas. By contrasting activity in these conditions, it is possible to examine whether observation of body movement is crucial in activating motor areas. Finally, by calculating the interaction between conditions (action or object–motion) and settings (live or TV), we can examine whether live and televised actions are processed differently. By utilizing these techniques, we then conducted an experiment with 6- to 7-month-old infants to examine the infant's brain responses to live and televised actions and objects (Experiment 2).

## Experiment 1

### Subjects

Twelve healthy adult subjects (five females and seven males; aged  $26.3 \pm 4.2$  (mean  $\pm$  SD) years, 18–33 years) participated in the experiments. All subjects were right-handed and had normal or corrected-to-normal vision. Written informed consent was obtained from all subjects. The experiments were approved by the local ethics committee.

### Procedure

Subjects observed two kinds of visual stimuli, which were either live or on TV: (1) a demonstrator performed an action with objects (action stimulus), (2) objects were manipulated by an invisible demonstrator (agent-induced object–motion stimulus or,

simply, object–motion stimulus). In the action stimulus, a right-handed male demonstrator picked up small balls and moved them towards a dish by using chopsticks. In the object–motion stimulus, a demonstrator who was invisible to the subject played quoits (the pole and quoits were visible to the subject). Those two actions were chosen since both actions contain goal-directed object-transfer manipulation with comparable hand and arm movement. We introduced another visual stimulus where an object was moving under physical laws (spontaneous object–motion stimulus or control stimulus). In the spontaneous object–motion stimulus, a ball hanging from the ceiling swung like a pendulum. The spontaneous object–motion stimulus served as a control stimulus and was presented alternately with the action or agent-induced object–motion stimulus. In the action observation condition, the action stimulus was presented for 6 s followed by a control period of 12 s. In the control period, the subjects watched the control stimulus for 6 s, while there was a 3-s blank period before and after presentation of the control stimulus to replace the experimental stimuli with the control stimulus. In the object–motion observation condition, the object–motion stimulus was presented in the same way as in the action observation condition. The demonstrator kept quiet throughout the experiment. In the live setting, the demonstrator sat at a table 2 m from the subject. In the TV setting, a liquid crystal monitor (SDM-S51, SONY) was set on a table 1 m apart from the subject. The visual angle was approximately  $31^\circ$  in both settings. The stimuli used in the TV setting were prepared to resemble the live setting as closely as possible (size, color, movements of the demonstrator, etc.). We applied a  $2 \times 2$  (conditions [action observation, object–motion observation]  $\times$  settings [live, TV]) within-subject factorial experimental design. Each subject conducted six trials for each condition, and thus, there was a total of 24 trials. The order of experimental conditions was counterbalanced across subjects.

A manual motor task (motor condition) was conducted before the main experiment to identify the motor areas that were activated when the subject performed an action. In the motor task, subjects were required to perform repetitive hand opening and closing with both hands at approximately 2 Hz for 6 s, followed by a 12-s rest period. The task consisted of eight trials.

### NIRS recordings

NIRS measurements were performed throughout the experiment. A multi-channel NIRS unit operating at 780-, 805-, and 830-

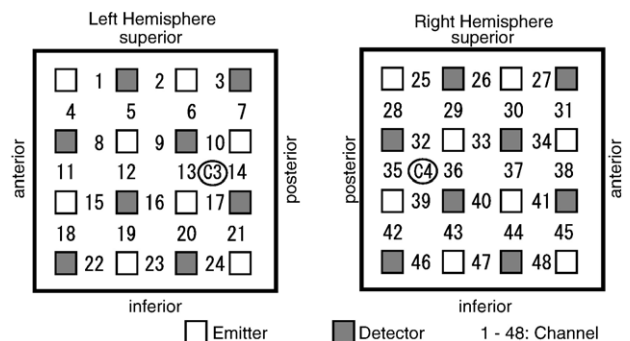


Fig. 1. Location of the optodes placed on the sensorimotor areas in both hemispheres. The distance between each emitter and the corresponding detector was set at 3 cm. C3 and C4 were located at the center between ch-13 and -14, and -35 and -36, respectively.

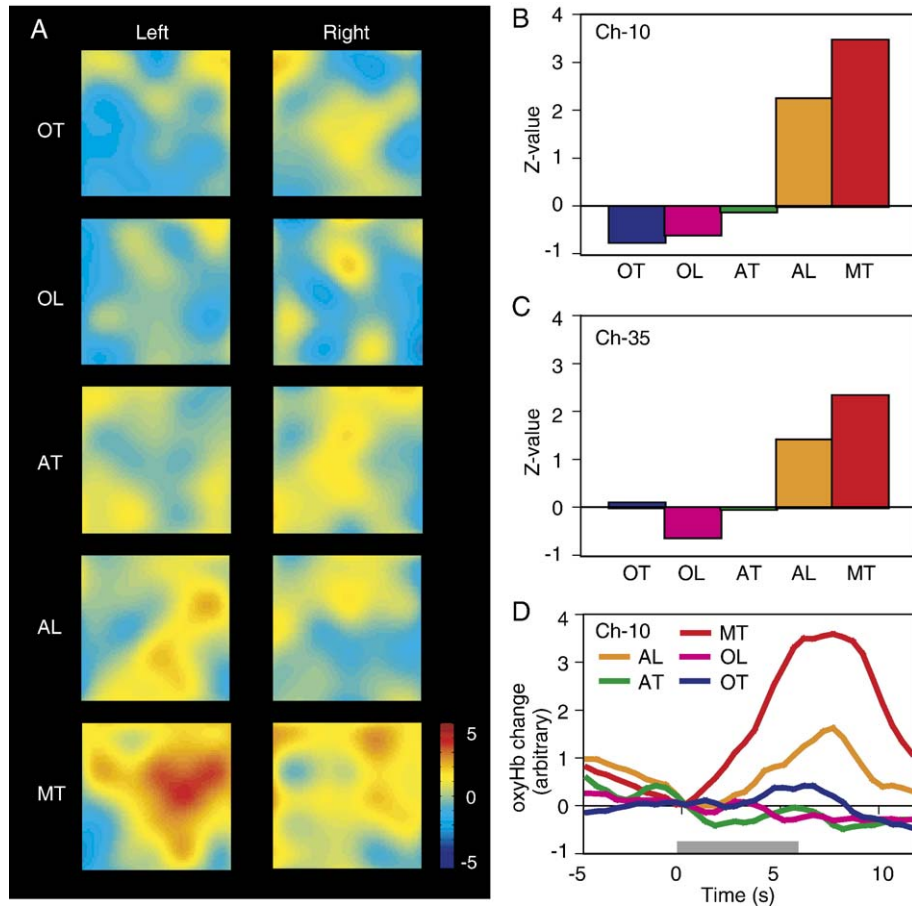


Fig. 2. (A) Z-maps of oxy-Hb for each condition contrasted against the control condition in the area measured (adult subjects). The arrangement of channels is the same as shown in Fig. 1. Ch-10 (left hemisphere;  $Z = 3.477$ ,  $P < 0.001$ ) and -35 (right hemisphere;  $Z = 2.345$ ,  $P < 0.01$ ) showed the largest activation in the motor condition (MT). (B) Z values for each condition contrasted against the control condition calculated by the general linear model at ch-10 and (C) ch-35. (D) The normalized NIRS responses (oxy-Hb) at ch-10 obtained from adult subjects. OT: object–motion observation in TV settings, OL: object–motion observation in live settings, AT: action observation in TV settings, AL: action observation in live settings, MT: motor conditions.

nm wavelengths (OMM-1080S, Shimadzu, Kyoto, Japan) was used to measure temporal changes in concentrations of oxy-hemoglobin (oxy-Hb), deoxy-hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb). Sixteen optodes constituted twenty-four channels and were placed upon the motor area of each hemisphere, including C3/C4 of the international 10/20 system in the caudal portion ( $9 \times 9$  cm square area, Fig. 1). Each channel consisted of one emitter optode and one detector optode located 3 cm apart from the emitter. The sampling rate at each channel was approximately 8 Hz.

The region of interest (ROI) was originally decided as being the primary motor area as described in the previous study (Jarvelainen et al., 2001). However, since the spatial resolution of NIRS is relatively low, the ROI was effectively decided as the area where channels showed the largest activation in the motor condition, and these were located near C3/C4 of the international 10/20 system. These channels were likely placed upon the pre- or post-central gyrus (Okamoto et al., 2004), and thus, in this paper, the ROI is referred to as the sensorimotor area.

#### Data analyses

Statistical analyses of the NIRS data were performed with a least-squares estimation using a general linear model (GLM)

(Friston et al., 1995; Schroeter et al., 2004a; Shimada et al., 2005) implemented with Matlab 6.1 (MathWorks, Natick, MA). The design matrix employed a 2-s-delayed box-car function convolved with a Gaussian kernel of dispersion of 4-s full-width half-maximum, which modeled temporal correlations in a NIRS time series.<sup>1</sup> The AR(1) model was used to adjust for autocorrelated error terms. The experimental condition period (action observation or object–motion observation) was contrasted against the control period. A group (random-effect) analysis was performed for each experimental condition with a one-tailed  $t$  test using individual contrast images (distinct from zero). A second-level analysis was performed with a paired  $t$  test, comparing the contrast images of all subjects between the action observation and object–motion observation conditions. Finally, to examine the difference between live and TV settings, contrast images of the action and object–motion observation conditions were tested with a paired  $t$  test (live [action–object] vs. TV [action–object]). The resulting  $t$  values were trans-

<sup>1</sup> We applied a 6-s-delayed box-car function in the infant experiment according to the waveform obtained in the experiment (Figs. 4C, D). Although we do not discuss this issue in detail, some studies have reported that hemodynamic responses are delayed in infants compared to adults (Schroeter et al., 2004b).

Table 1

Z values of oxy-, deoxy-, and total-Hb for each experimental condition contrasted against the control condition at ch-10 in adult subjects

	Live			TV		
	oxy-Hb	deoxy-Hb	Total-Hb	oxy-Hb	deoxy-Hb	Total-Hb
OO	-0.590	1.348	0.953	-0.747	0.523	-1.139
AO	2.249*	-1.281	-0.321	-0.112	0.064	-0.208
MT	3.477**	-1.129	1.489			

OO: object–motion observation, AO: action observation, MT: motor condition.

\*  $P < 0.05$ .

\*\*  $P < 0.01$ .

formed into  $z$  values. Since we had a strong a priori hypothesis on activation foci (namely, the sensorimotor area), the threshold level was set at  $P < 0.05$ . Although each NIRS parameter was analyzed, we mainly report here the results of oxy-Hb because we consider that oxy-Hb is the most sensitive parameter of hemodynamic responses (Hoshi et al., 2001; Strangman et al., 2002; but see Schroeter et al., 2004a).<sup>2</sup>

Additionally, in order to see the time aspect of the conditional difference in NIRS data, we examined the waveform of hemodynamic responses with a continuous (time-series) version of the ‘effect size’ analysis (Matsuda and Hiraki, 2006, see also Schroeter et al., 2003). In the waveform analysis, we utilized the individual standard error of the NIRS data in the control period to normalize the NIRS time series data in the experimental condition periods. This normalization enabled the comparison of NIRS data among subjects. Conditional differences in waveforms were tested with one-tailed  $t$  tests by using samples at each time-point to determine during which time the responses in action observation were larger than those in object–motion observation. The difference between the live and TV settings was similarly examined by comparing subtracted NIRS time series data (action–object) in the live and TV settings. In order to reduce type I errors, only the durations where conditional differences ( $P < 0.05$ ) lasted more than 1 s were considered significant.

## Results

Fig. 2A depicts  $z$ -maps of oxy-Hb for each condition calculated by the GLM group-level analysis. Channels located close to C3/C4 showed the largest activation in the motor condition, indicating that these channels were located upon the sensorimotor area (ch-10,  $Z = 3.48$ ,  $P < 0.001$ ; ch-35,  $Z = 2.34$ ,  $P < 0.01$ ; there was no significant difference between hemispheres). Ch-10 in the left hemisphere showed a significant activation in the action observation condition in the live setting ( $P < 0.02$ ; Table 1), although ch-35 in the right hemisphere did not show a significant activation ( $P = 0.08$ ; Table 2). In other conditions, neither channel showed significant activation (Figs. 2B, C). It is worthwhile mentioning that ch-10 showed the highest activation both in the motor and live action observation conditions, and no channels were activated in other conditions. Ch-16 and -20

were also activated both in the motor and the live action observation conditions ( $P < 0.05$ , uncorrected) although the activities were lower than ch-10. These results suggest that the area we measured by NIRS exhibited cortical activation with similar spatial distribution in the motor and live action observation conditions, which seem not to be affected by differences of the actions employed. In the right hemisphere, no channels showed activation in the action or object–motion observation conditions.

The second-level GLM analysis revealed that the activation in ch-10 was larger in the action observation condition than in the object–motion observation condition in the live setting ( $P < 0.01$ ), but not in the TV setting ( $P > 0.3$ ). Ch-35 did not show a significant difference between conditions ( $P = 0.08$  in the live setting, and  $P > 0.4$  in the TV setting). The interaction (condition  $\times$  settings) did not reach a significant level in either channel ( $P > 0.1$ ). Since ch-35 did not show any significant activation in action observation conditions, further analyses were focused on ch-10.

We conducted waveform analyses on ch-10 to examine the time aspect of the conditional difference (Fig. 2D). Comparison between conditions in the live setting revealed that the activity was larger in the action observation condition than in the object–motion observation condition during 10 to 13 s after task onset ( $P < 0.03$ ). This difference was not observed in the TV setting ( $P > 0.3$ ). Comparison of the subtracted waveform (action–object) between the live and TV settings showed that there was a significant difference (an interaction between conditions and settings) at around 13 s ( $P < 0.05$ ), suggesting that the effect of body movement observation on sensorimotor activity was different between live and TV settings.

## Experiment 2

In Experiment 1, we showed that NIRS was capable of measuring sensorimotor activation during action observation in adults. This activity was significantly larger in action observation than in object–motion observation in the live setting but not in the TV setting. In Experiment 2, we then conducted similar experiments with infant subjects to investigate whether the same neural responses were obtained from infants.

## Subjects

Thirteen 6- to 7-month-old infants (eight females and five males:  $210 \pm 6.2$  (mean  $\pm$  SD) days old, 201–220 days) participated in the experiments. Another five infants participated but were not included in the analysis due to NIRS measurement

Table 2

Z values of oxy-, deoxy-, and Total-Hb for each experimental condition contrasted against the control condition at ch-35 in adult subjects

	Live			TV		
	oxy-Hb	deoxy-Hb	Total-Hb	oxy-Hb	deoxy-Hb	Total-Hb
OO	-0.623	0.125	0.061	0.103	0.814	1.424
AO	1.417	-0.831	-0.827	-0.034	0.646	1.387
MT	2.344**	-1.035	1.326			

OO: object–motion observation, AO: action observation, MT: motor condition.

\*\*  $P < 0.01$ .

<sup>2</sup> Previous studies with infants (Baird et al., 2002; Taga et al., 2003) and our pilot observation (Fig. 3E) indicate that oxy-Hb showed relatively consistent responses across trials and subjects, while deoxy-Hb showed variable changes.

Table 3  
Coding of arm and hand movements

Level	Description
0	No movement
1	Small arm movement/no arm movement but hand movements
2	Large arm movement
3	Swinging the arm roughly

failure; crying ( $N = 4$ ) and slippage of probes due to large head movements ( $N = 1$ ). The infants were assigned to either the TV or the live group (seven in the TV group, and six in the live group). Infants who accomplished more than one session were included in the analyses (five in the TV and four in the live group completed the entire experiment). All parents of infants gave written informed consent after explanation of the experiment. The experiments were approved by the local ethics committee.

Hand preference was judged by analyzing video-recordings of the experiment. Right and left arm movements were coded into four levels (Table 3) on a second-by-second basis. Summation of these scores throughout the experiment was used for judgment. All but four infants used their right hands preferentially (right-hand use >50%); three subjects used both hands nearly equally (50%), and only one subject used the left hand preferentially (<50%).

#### Procedure

The procedure was similar to the adult experiment, although several parts of the experiment were altered to suit infant subjects (see below). In the action observation condition, subjects were shown a female demonstrator manipulating an attractive non-commercial toy (when the demonstrator tapped lateral parts of a box, a gadget installed inside the box sprung out). In the object–motion observation condition, a toy was manipulated by the

Table 4  
Percentages of infant's looking time (%) for each experimental stimuli (mean  $\pm$  SD)

	OO	AO	CT
Live	92.4 $\pm$ 6.0	93.3 $\pm$ 5.2	85.5 $\pm$ 3.2
TV	96.1 $\pm$ 1.9	93.6 $\pm$ 8.0	80.8 $\pm$ 6.2

OO: object–motion observation, AO: action observation, CT: control stimuli.

demonstrator who was invisible, but still audible, to the infants (a gadget on a wall moved up and down, manipulated with a cord held by the demonstrator). In the control stimulus, the infants watched an object moving under physical laws (a ball hanging from the ceiling and swinging like a pendulum). These stimuli were presented either through a TV monitor (KW-28HDF7, SONY) or were live. The viewing distance was held constant at approximately 130 cm. The visual angle was approximately 43° in both conditions. During presentation, the demonstrator talked to the infant, such as ‘Watch this!’ or ‘Isn’t it funny?’ to encourage the infant to engage in the experiment. The vocalization and performance of the demonstrator were matched as closely as possible between the live and TV settings.

The experimental condition stimulus and the control stimulus were presented consecutively and repeatedly as in the adult experiment (Fig. 3D). This configuration is more effective in attracting the infants’ attention throughout the experiment than using a rest period (Taga et al., 2003). Each experimental condition stimulus was presented three times (20 s for each) separated by a control period (20 s). In the control period, the infant watched the control stimulus for 10 s, while the demonstrator hid behind the screen. At the beginning and end of the control period, there was a 5-s interval where the stage was occluded by a curtain to change the experimental setting. The subjects participated in one object–motion observation condition session and two action observation

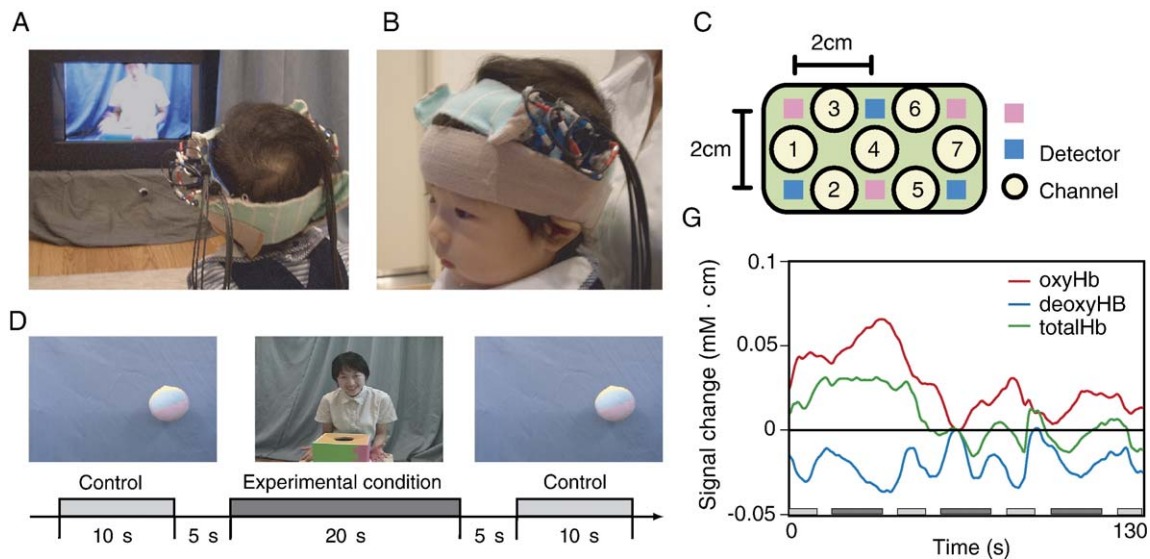


Fig. 3. (A) Experimental settings. The infant was seated on the parent's lap. (B) The NIRS probes were attached to the motor areas by using a custom-made holder and a soft headband. (C) Arrangement of the NIRS channels. Each channel consisted of one emitter optode and one detector optode. The distance between optodes was 2 cm. Ch-7 was located upon C3 of the 10/20 system. (D) Schematic illustration of the experimental procedure. The stimuli were presented either through a TV monitor or were live. The infant was presented with the control and experimental condition stimuli consecutively and repeatedly. (E) Hemodynamic responses during action observation at ch-4 in a 6-month-old infant. The duration of experimental stimulus presentation is indicated with a gray bar.

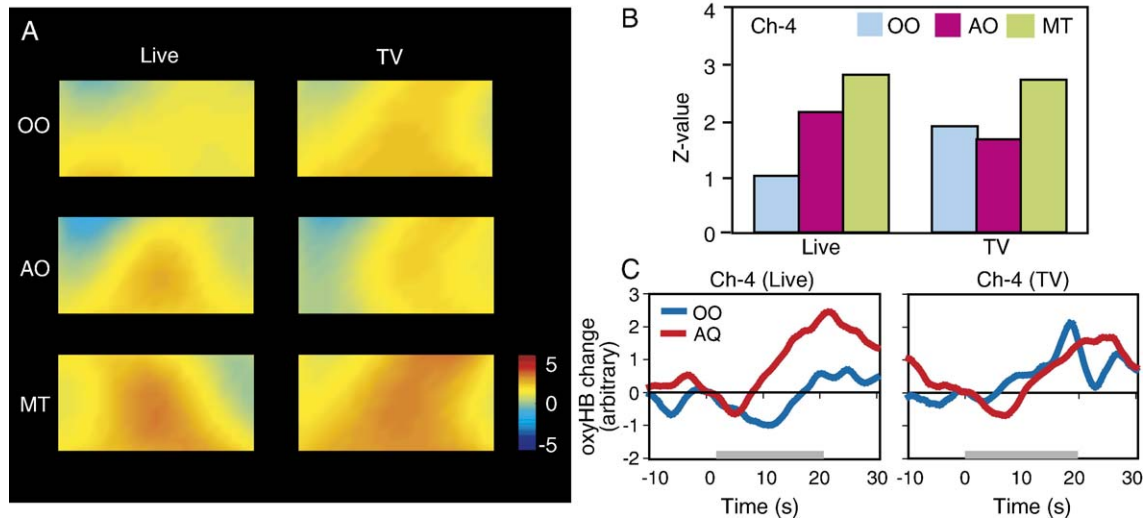


Fig. 4. (A) Z-maps of oxy-Hb for each condition contrasted against the control condition in the left sensorimotor area (infant subjects; see Fig. 3C). The activity in the free-play session (motor condition) is also shown at the bottom (MT). Ch-4 was strongly activated both in the live ( $Z = 2.70$ ;  $P < 0.003$ ) and TV groups ( $Z = 2.93$ ;  $P < 0.002$ ). (B) Z values at ch-4 for each condition contrasted against the control condition calculated by the general linear model. The activity in the motor condition is also shown (MT), which was calculated for the live and TV groups separately. (C) The normalized NIRS responses (oxy-Hb) at ch-4 in the live and (D) TV groups. The experimental stimulus was presented from time 0 s through 20 s (indicated with a gray bar). OO: object–motion observation, AO: action observation.

condition sessions; this treatment was due to our pilot observation that infants tended to make more movements in action observation conditions. The order of experimental conditions was counter-balanced across subjects. To confirm that the infants were attentive in the experimental settings, we measured looking time for each stimulus. The infants were quite attentive in the experimental settings as the percentage of looking time exceeded 80% in all conditions (Table 4). There was no significant difference in looking time between action observation and object–motion observation conditions in either setting ( $P > 0.1$ , paired  $t$  test) or between live and TV settings for each condition ( $P > 0.1$ ).

Functional identification of the sensorimotor areas was somewhat complicated in the infant experiment since it is impossible to give instructions to infants. In order to identify the sensorimotor areas that were active when the infant themselves performed an action, we set up 1-min sessions before and after the experimental sessions, in which the infants who were seated on their parent's lap could freely play with toys. In these free-play sessions, the experimenter and the parent refrained from acting or talking to the infant. The infant's behavior was video-recorded, and the magnitude of movement of the right arm was coded into four levels (level 0–3; see Table 3) on a second-by-second basis by two observers (the matching rate was 84%). The period that contained adequately large arm movements (level 2) towards the toys that lasted at least 2 s surrounded by sufficient non-movement (level 0 or 1) periods (a minimum of 5 s before the movement and 3 s after the movement) was extracted ( $3.8 \pm 2.2$  samples per subject, mean  $\pm$  SD; motor condition). We performed GLM analyses (see above) using NIRS data in these samples to identify the most activated channels as the sensorimotor area.

### Recordings

Six optodes were placed on the left sensorimotor area to form seven channels by using a custom-made holder, including C3 of

the international 10/20 system in the caudal portion ( $2 \times 4$  cm square area, Figs. 3B, C).<sup>3</sup> Optical fibers were optimally attached to the holder to enable stable measurement against bodily movement of infants. The interoptode distance was set at 2 cm. The sampling rate in each channel was 10 Hz.

In the infant experiment, we attempted to minimize contamination of the NIRS signals from cortical activation related to arm movement of the infant per se during action observation. Thus, if the infants moved their own arm during action observation, the NIRS signals should partly reflect cortical activation related to the arm movement itself. For this purpose, two observers coded the magnitude of the infant's movement during each task and control period. The matching rate between observers was 88%. If the infant's movement was larger in the experimental condition period than in the preceding control period, or the infant's movement was considerably large in the experimental condition period, the trial was rejected. Since it is very difficult to ensure that infants do not move while viewing stimuli, we did not discard trials where small movements were observed in both the control and experimental condition periods or only in the control period. According to this criterion, 15% of trials were rejected. NIRS data that contained significant measurement artifacts were discarded by trial-by-trial inspection in each channel (additional 13% of trials were rejected). A measurement artifact was defined as a signal change in which two successive NIRS signals were separated by more than three standard errors of the entire data of

<sup>3</sup> The right sensorimotor areas were also measured but not analyzed since most of the channels located on the right hemisphere were contaminated by considerable measurement artifacts. We consider that this was because the optic fibers set on the right hemisphere were put between the infant and the parent's torso (the infant seated on the parent's lap), so that these fibers most likely suffered from bodily movements of both the infant and the parent. In contrast, the fibers located on the left hemisphere were directly connected to the NIRS apparatus, so that these fibers were much more tolerant of movements of the infant and the parent.

Table 5

Z values of oxy-, deoxy-, and Total-Hb for each experimental condition contrasted against the control (baseline) period at ch-4 in infant subjects

	Live			TV		
	oxy-Hb	deoxy-Hb	Total-Hb	oxy-Hb	deoxy-Hb	Total-Hb
OO	1.009	-1.029	0.499	1.893*	-0.431	0.931
AO	2.139*	-0.033	1.516	1.661*	-0.526	0.630
MT	2.805**	-0.877	1.073	2.713**	-1.055	0.412

Note that activity in the motor condition was calculated for the live and TV groups separately.

OO: object–motion observation, AO: action observation, MT: motor condition.

\*  $P < 0.05$ .

\*\*  $P < 0.01$ .

the corresponding task or control period. Only the resulting data (TV-object, 14 trials; TV-action, 24 trials; live-object, 14 trials; live-action, 15 trials) were submitted to further analyses as in the adult experiment.

## Results

We found that ch-4 (Fig. 3C) was strongly activated when the infants acted towards the toys in the free-play sessions (motor condition) both in the live ( $P = 0.003$ ) and TV ( $P = 0.002$ ) groups, which indicated that ch-4 was located at the sensorimotor area (Figs. 4A, B). In the live group, ch-4 was activated in the action observation condition ( $P < 0.02$ ) but not in the object–motion observation condition ( $P > 0.1$ ). In the TV group, ch-4 was activated in the action observation condition ( $P < 0.05$ ) as well as in the object–motion observation condition ( $P < 0.03$ ). Second-level GLM analyses found no significant conditional differences in both groups. The results are summarized in Table 5. No channels showed greater activation compared to ch-4 in any conditions ( $P > 0.1$ ; paired  $t$  test).

We then performed waveform analyses and found conditional differences similar to those observed in the adult experiment. In the live group, differences between the action and object–motion observation conditions were found during 15–16 s after task onset (Fig. 4C;  $P < 0.05$ ). However, this difference was not observed in the TV group (Fig. 4D;  $P > 0.3$ ). By comparing the subtraction of waveforms (action–object), only marginal differences between the live and TV groups were found during 15–16 s after task onset ( $P = 0.15$ ).

## General discussion

This study aimed to examine whether adult and infant brains respond to a televised action or object in the same way as to a live one. The experiment with NIRS measurements demonstrated that both in adults and infants, the sensorimotor area was more activated when observing an action of others compared to object movement in the live setting, while this was not evident in the TV setting. Although our results were preliminary rather than decisive, these results suggest that body movement observation affects activity in the sensorimotor areas differently between the live and TV settings, indicating that live and televised actions are differently processed in the adult's and infant's brain.

## Activation during action observation in infants

Our results show for the first time that the infant's motor areas, which were activated when the infant themselves performed an action, were also activated during observation of another's action. Since the experimental condition periods were directly compared with the control period, activity in the sensorimotor area did not reflect the general movement of an object. Neither did the sensorimotor area respond merely to vocalization of the demonstrator, since the infants also heard the demonstrator in the object–motion observation condition where activation was not observed in the live group. In our experiment, the sensorimotor area was identified as the channel that showed the highest activation in the free-play sessions where the experimenter and parent were prohibited from talking to the infants (Fig. 4A). Contamination of motor activity of infant movement per se was minimized (see above). In addition, the infants were quite attentive to the stimuli in all conditions ( $>80\%$ ). Therefore, we conclude that the infants' motor areas responded to the sight of the demonstrator performing an action.

The involvement of the sensorimotor area in action observation has been repeatedly reported in adult studies. Using magnetic transcranial stimulation (TMS), the primary motor area (M1) has been shown to be engaged in observation of an action performed by others (Fadiga et al., 1995; Maeda et al., 2000). Several magnetoencephalographic (MEG) studies also showed that the sensorimotor areas are activated during action observation (Avikainen et al., 2002; Jarvelainen et al., 2004; Hari et al., 1998; Nishitani and Hari, 2000). Behavioral studies on motor facilitation are consistent with these results (Meltzoff and Prinz, 2002). Recently, Raos et al. showed that M1 was engaged in action observation in monkeys using the  $^{14}\text{C}$ -deoxyglucose method (Raos et al., 2004). Given that there are strong anatomical connections between M1 and the ventral premotor area, one possible hypothesis on activation in the sensorimotor area during action observation is that M1 receives facilitatory input from the ventral premotor area where mirror-matching activity was frequently observed.

Although the functional role of activation in motor areas during action observation is still under debate, we stress that it has a central role on implicit action simulation and motor memory. It is well demonstrated that action observation activates neural circuits engaged in motor imagery, which is equivalent to simulating or rehearsing an actual motor act (Fadiga and Craighero, 2004; Gallese, 2003). A recent study showed that the expert dancer showed stronger brain activity when viewing dance actions compared to other actions that were not within the expertise of the dancer, indicating that the motor activity in action observation is likely dependent on the motor repertoire of the observer (Calvo-Merino et al., 2005). It is known that imitation capability is remarkably developed during the second year of life, and it is plausible that abilities such as perception of the other's intention and joint attention greatly enhance the infant's imitation ability (Tomasello, 1999). However, imitation is also possible by newborn infants (Meltzoff and Moore, 1977) as well as 6- to 9-month-old infants (Learmonth et al., 2004; Collie and Hayne, 1999). Therefore, we suggest that 6-month olds are capable of internally simulating novel movements performed by others by assembling primitive (component) movements in their motor repertoire. We coded the infant's behaviors towards the toy in the free-play sessions. Although the exact arm movement that the demonstrator did in the experiment (patting the side part of the toy) was hardly

performed by infants (only one infant did so), similar arm movements (patting the top of the toy) were observed in ten out of thirteen infants. This indicates that the arm movement (patting an object) was to some extent retained in the movement repertoire of the infants, and that the activity in the sensorimotor area that we observed may reflect activation of this action representation.

#### *Difference in activation between live and TV settings*

Our results suggest the possibility that the difference in sensorimotor activity between action observation and object–motion observation is likely modulated by how the stimuli were presented, i.e., live or on TV. This is consistent with a previous MEG study with adults, which showed that M1 activity during action observation is larger in the live condition than in the TV condition (Jarvelainen et al., 2001). However, we did not observe activation during action observation in the TV setting in adults, while the previous study reported a significant activity in the TV setting. This can be explained by the difference in the control stimuli used in both experiments; we asked subjects to view a moving object during the control period, while in the previous study, the subject was fixated on a point in the control period. Thus, the activity observed in the TV setting in the previous study may reflect activity related to the processing of a moving object, which was canceled out in our experiment.

The different effect of action observation on sensorimotor activity between the live and TV settings was similarly observed in infants, although it did not reach a significant level (probably due to the ‘weak’ experimental design we employed; i.e., we used a between-subject design for the infant experiments, instead of the within-subject design used for the adult experiments). In the live setting, activity in the sensorimotor area was sensitive to whether body movement of others was presented, whereas this was not the case in the TV setting. A developmental study, which demonstrated that the infant’s imitation performance was different between live and TV settings, seems consistent with our findings (Barr and Hayne, 1999). However, we obtained an unexpected result in that the sensorimotor area of infants was activated both in the action and object–motion observation conditions in the TV setting. We believe that these results should be interpreted cautiously since we did not observe similar activity in the adult experiment. In addition, the number of subjects who participated in the present experiment was relatively small, and thus, further studies are required to confirm this finding. Nevertheless, it seems possible that observation of an object induces the intention to manipulate the object and simulation of the intended action. In fact, motor areas were activated during simple observation of a static object in human adults (Grafton et al., 1997; Grezes and Decety, 2002) and monkeys (Murata et al., 1997). Visual imagery of an object (expanding/shrinking light bar) also facilitates arm and hand motor representations in M1 (Fadiga and Craighero, 2004). These studies indicate that observation of a static or moving object can activate motor representation of the appropriate action to some extent. Interestingly, a recent developmental study showed that 17-month-old infants were capable of imitating (emulating) an object manipulation action even though the demonstrator’s body parts were edited out (in digitally modified videos) (Huan and Charman, 2005). While the mirror-matching mechanism seems valid with regard to immediate imitation in neonates (Meltzoff and Moore, 1977) and unconscious mimicry in adults (Chartrand et al., 2005), as well as our observation in the live setting, a more comprehensive

theory of activating motor areas by viewing visual stimuli is required.

Our results demonstrate that the sensorimotor activity was more pronounced in response to an action of others than to object movement in the live setting, while it was not observed in the TV setting. This difference may reflect different processing of body movement of others between live and TV settings. One possible hypothesis is that a televised person is less effective in eliciting internal processing of another’s action compared to a live action, so that body movement is processed similarly to object movement. The difference between 2D and 3D presentation might contribute to this effect. Another hypothesis is that a person manipulating an object is internally complemented in the observer’s brain even though only the object is directly shown to the observer. We speculate that this effect occurs only in the TV setting, since the observer is aware that they are not able to watch the entire virtual space where televised objects and persons ‘exist’, due to limitation of the screen size of the TV monitor. Currently, we cannot determine which hypothesis is more plausible, as adults and infants showed inconsistent activities in the TV setting (it is reasonable to consider that adults tended to inhibit responses to the stimuli presented on TV compared to infants, by learning through their experience that televised stimuli are not ‘real’). The present study suggests that television offers a different reality in the observer’s brain compared to the live setting and thus does not merely attenuate brain responses to visual stimuli. Television is equipped with the limited physical space of a video screen where people and objects move discontinuously with the real world. We cannot directly interact with them as we do in the live setting, whereas it may be more effective in attracting observer’s attention. Presentation techniques, from zooming to computer graphics employed in broadcast TV programs, provide us with experiences far beyond those we experience in the real world. The present study propounds the idea that the human brain, in both adults and infants, responds differently to live and televised stimuli. The important question to be further investigated is how and to what extent the grammar of TV (visual presentation techniques), as well as physical characteristics (i.e., two dimensionality, size, color), affect neural responses in the observation of televised actions and objects.

#### *Technical issues*

Finally, some technical issues should be discussed. First, NIRS is advantageous in measuring brain activity in various naturalistic situations as well as in measuring infant brain responses. However, its lower spatial resolution made it difficult to identify the exact anatomical region of the activated foci. In the present experiments, we conducted simple motor tasks to ensure that the probes were placed upon the sensorimotor area. Channels that exhibited the highest activity in the motor tasks were located near C3 or C4, confirming that those channels were likely placed upon the pre- or post-central cortex (Okamoto et al., 2004). We postulate that these channels were likely to have been located on M1, although it is still possible that these channels included the primary somatosensory area (S1) and premotor areas. In fact, ch-4 in the infant experiment was located slightly anterior (2 cm) to C3. This may reflect the methodological difference between the adult and infant experiments in the functional identification of the sensorimotor area; that is, the adults performed a simple motor task whereas a reaching movement was employed in the infant subjects to identify the sensorimotor area. To say the least, in the NIRS measurement it is preferable to use

both skull surface labeling (the international 10/20 system) and functional assessment to identify the anatomical location of the measured area, wherever possible. Secondly, in the statistical (GLM) analyses, we employed a box-car function to detect functional activation both in adults and infants. However, it has not been well investigated whether the infant brain shows the same hemodynamic responses as adults. We applied a 6-s-delayed box-car function in the infant experiment, in contrast to a 2-s-delayed box-car function in the adult experiment, according to the waveform of the hemodynamic responses observed in the infant experiment (Figs. 4C, D). This is consistent with one NIRS study, which reported that hemodynamic responses are temporarily shifted in children compared to adults (Schroeter et al., 2004b). However, further experiments are needed to confirm this finding. In addition, we should be cautious in saying that similar cortical activation reflects similar functionality in the measured areas between adults and infants, since anatomical structures of the brain are substantially different between these two age groups (Matsuzawa et al., 2001). Thirdly, our NIRS apparatus used wavelengths between 780 and 830 nm. However, recent studies have suggested that it is better to use lower wavelengths (i.e., 690 nm) to avoid cross talk between oxy-Hb and deoxy-Hb (Uludag et al., 2004; Strangman et al., 2003), and by choosing the best combination of wavelengths, the signal-to-noise ratio in the NIRS measurements may be improved. Nevertheless, we believe that the results obtained from the conventional NIRS apparatus were sufficiently reliable, as in a previous study, a NIRS apparatus using wavelengths similar to ours demonstrated good consistency with fMRI BOLD signals (Strangman et al., 2002). Finally, we tried to avoid contamination of the motor activity induced by the infant's movement per se to the activity caused by action observation. It is obvious that it is impossible to avoid any movement of awake infants during the experiment. We coded the infant's movements during the experiments and rejected trials where the infant's movement was larger in the task period compared to the control period. Although we cannot confirm that the measured brain activity does not include any motor activity of infant movement, we are confident that the ratio of the contamination was substantially reduced by this technique. NIRS provides us with a means of investigating infant brain activity in various cognitive tasks. However, a more sophisticated experimental design to solve several problems inherent in infant experiments needs to be explored.

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