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Neural basis of learning from television in young children

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Abstract

It has been shown that preschool children can learn as well from video presentations as from live presentations in word acquisition, action imitation, and object searching. Several cognitive theories have been proposed to explain the developmental changes accompanying the onset of learning from TV, but the underlying neural mechanism is unclear. One possible mechanism is the mirror-matching system, in which observation of action recruits an observer's internal motor representation of the same action. Using near-infrared spectroscopy, we examined whether sensorimotor regions are activated when children learn rule-based actions from a live model versus a televised model. The results revealed that children learned the actions equally well from both live and televised models, but activations in the left sensorimotor regions were marginally stronger when learning from the live model than from the televised model. These results may contribute to our understanding of how to support children's learning from television.

Key words: learning from TV, NIRS, young children, mirror-matching system, motor cortex

Introduction

Television or video (TV) viewing and its relationship with cognitive and social development are important issues in child development research. Interest is widespread in the question of whether, and how early, exposing infants and young children to TV is harmful or good for cognitive and brain development, and this remains a controversial issue in developmental psychology, education, neuroscience, and pediatric research (Christakis, Zimmerman, DiGiuseppe, & McCarty, 2004; Courage & Howe, 2010; Foster & Watkins, 2010; Landhuis, Poulton, Welch, & Hancox, 2007). Parents and teachers are also interested in the related issue of how readily infants and children learn language, actions, and new skills from television programs, videos, or DVDs (Barr & Hayne, 1999; Kuhl, Tsao, & Liu, 2003; Rice, Huston, Truglio, & Wright, 1990).

It has been shown repeatedly that by age 3, children begin to learn as well from video presentations as from live presentations, in word learning, action imitation, and object search tasks (Hayne, Herbert, & Simcock, 2003; McCall et al., 1977; Moriguchi, Sanefuji, & Itakura, 2007). On the other hand, children under 3 years of age typically fail to learn actions or vocabulary from video media, which is referred to as “video deficit” (Anderson & Pempek, 2005; Kuhl, 2007; Robb, Richert, & Wartella, 2009; Troseth &

DeLoache, 1998). Several cognitive theories have been proposed explain the developmental changes that lead to teachability by TV. One theory is that the developmental change is due to an improvement in perceptual encoding; 2-dimensional video presentations include less information than 3-dimensional live presentations, allowing children to encode only the latter (Barr & Hayne, 1999). Other researchers have explained the phenomenon in terms of ability to understand symbolic representations. According to this theory, younger children may fail to represent the relationship between images on television or video (a symbol) and real objects (a referent) (Troseth & DeLoache, 1998). An eventual understanding of the dual representation is postulated to make children's learning from TV easier.

Although the neural mechanism of learning from TV remains unclear, the issue is being argued in the context of understanding another person's actions. There is a growing body of data from infant, child, and adult subjects regarding the neural mechanism of the understanding and learning of another person's actions. It is well established that observation of actions recruits the observer's internal motor representation of the same actions. Indeed, several brain regions (e.g., the primary motor and premotor cortices) involved in executing actions are also activated by the mere observation of such actions. This "mirror neuron" system has been described in both humans and monkeys (Buccino et

al., 2001; Nishitani & Hari, 2000; Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996).

The developmental origin of the mirror-matching system is still under debate (Ferrari et al., 2012). Nevertheless, electroencephalographic (EEG) and neuroimaging research has revealed that the mirror neuron system may be functional during early infancy (Lepage & Théoret, 2007; Marshall & Meltzoff, 2011; Shimada & Hiraki, 2006). Indeed, Shimada and Hiraki (2006) used near-infrared spectroscopy (NIRS) to show that 6-month-old infants activated the primary motor regions when observing another person's actions. Moreover, EEG research has shown that mu-rhythm desynchronization, which was assumed to be an index of activity in the mirror-matching system, was observed in 8- and 9-month-old infants while they viewed another person's actions (Nyström, Ljunghammar, Rosander, & von Hofsten, 2011; Southgate, Johnson, El Karoui, & Csibra, 2010). More recently, Turati et al. (2013) reported that this mu-rhythm desynchronization effect may emerge as early as 6 months of age (see also Nyström, 2008).

Activation of the mirror-matching system in infants and young children may depend on context, familiarity with the observed actions, and motor ability (Cuevas, Cannon, Yoo, & Fox, 2013; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008;

Warreyn et al., 2013). Notably, activation was also affected by the modality of the presentation of another person's actions. Indeed, NIRS studies showed that the primary motor cortex was recruited in 6-month-old infants when they observed either live or televised actions, but the pattern of activation was different (Shimada & Hiraki, 2006). In an EEG study, Ruysschaert, Warreyn, Wiersema, Metin, & Roeyers (2013) presented 18- to 36-month-old children with either goal-directed hand movements or with the same actions in non-goal-directed contexts, either live or on video. Significant mu-rhythm desynchronization occurred only for live, goal-directed actions.

In summary, behavioral research shows that children fail to learn from TV until 3 years of age, but that 4- and 5-year-old children readily learn actions and words in this modality. According to brain research, the mirror-matching system may function during early infancy, but the system activations may differ across live vs. TV presentations in 1-3–year-old children. Given the evidence, it was expected that children of ages 4 or 5 activate the mirror-matching system when presented with actions on TV as well as when the actions are presented live.

However, it is also possible that children's brains differentiate televised actions from live actions. Neuroimaging has shown that adult participants recruit different brain

regions when passively observing live actions vs. televised (Järveläinen, Schürmann, Avikainen, & Hari, 2001; Perani et al., 2001; Shimada & Hiraki, 2006). Live actions activated brain regions related to the understanding of action, such as the mirror-neuron network, which includes the primary motor cortex and the right posterior parietal cortex. However, televised actions did not recruit such networks, but instead activated sensory areas such as the lateral occipital cortex. Given the evidence, children may show different activations in the mirror-matching system while viewing televised actions compared to live actions.

In the present study, we examined whether activation of sensorimotor areas during action learning is different depending upon whether young children learn from live or televised demonstrations. Importantly, we examined whether children exhibit differing patterns of brain activation in different learning modalities even with equivalent behavioral performances across modalities. We used an NIRS technique to monitor cerebral hemodynamics, by measuring changes in the attenuation of near-infrared light passing through tissue. Because NIRS is non-invasive and does not require the body to be immobilized (unlike, for example, functional MRI), it is suitable for brain imaging studies in infants and young children (Moriguchi & Hiraki, 2009).

Fifteen 5- and 6-year-old children were provided with five sessions each of a rule-learning task from a live model and a televised model, wherein the model sorted cards according to either color or shape rules, and the children had to sort the same cards according to the same rules (Figure 1A). Moreover, fifteen adult participants were given ten sessions of the same task. Each session consisted of a first rest phase, an observation phase, a second rest phase, and an execution phase. Brain activation was examined during the sessions using a multichannel NIRS system that covered the region of interest (ROI), which was located at around C3/4 of the International 10/20 system (Figure 1B), and included sensorimotor areas measured in previous research (Shimada & Hiraki, 2006). The spatial resolution of NIRS is relatively low, and therefore channels (ch) 4, 6, 7, and 9 (left primary motor area) and 15, 17, 18, and 20 (right primary motor area) roughly correspond to C3 and C4, respectively. We measured brain activation in each hemisphere separately under live and video conditions.

Material and Methods

Participants

Fifteen right-handed healthy adults (aged 25.3 ± 4.5 years [mean ± SD]; 7 males and 8 females) and 15 right-handed children (aged 72.7 ± 7.0 months [mean ± SD]; 8 boys

and 7 girls) participated in this study, but 2 children failed to complete the experiment and were excluded from the analyses. All children were from middle-class backgrounds, as assessed from parental reports. Adult participants provided informed consent for the study. For the children, parents provided written informed consent and were apprised verbally of the purpose of the study and the safety of the NIRS experiment. The study was conducted in accordance with the principles of the Declaration of Helsinki, and the study design was approved by the local ethics committee.

Behavioral tasks

Laminated cards 3.5 cm × 7.0 cm were used as stimuli. The stimuli had two dimensions: shape and color. The task required the use of target cards and test cards; target cards matched test cards in one dimension, but not in the other (e.g., target card: a red star and a blue cup; test card: a red cup and a blue star). The present experiments included five pairs of target and test cards, each of which was different in shape and color. Five pairs of target trays, each containing target cards, were used. Each stimulus was used twice for an adult participant and once for a child, under both live and video conditions. The entire experiment was videotaped regardless of participant age.

Adult participants were administered ten consecutive test sessions under each condition. One session consisted of a first rest phase (10 s), an observation phase (10 s), a second rest phase (15 s), and an execution phase (10 s). Prior to the experiment, participants were instructed to sit still and to observe a fixed point on a computer screen during the rest phases, to observe a female model's actions during the observation phases, and during the execution phases to sort the cards in a way similar to that of the model. Participants were not given any information before the experiment regarding the model's method of sorting the cards.

In the experiment, no instructions were given to the participants during the rest phases. During the observation phases, live or televised demonstrations were presented. Under live conditions, a female experimenter sorted the cards in the presence of the participants four times according to either a shape or a color rule. Under video conditions, videos were presented in which the same model sorted the cards four times, according to the shape or color rule. The participants were obliged to observe the demonstrations carefully because the model sorted the cards quickly and the rule used (color vs. shape) was different across sessions. During the execution phases, participants were given four cards consecutively and were instructed to sort the cards according to the observed rules.

Children were administered five consecutive test sessions under each of the live and the video conditions. The procedure was approximately the same as that for adult participants, except that children were asked to observe a static cartoon character's image on the computer screen during the rest phases. We did not use animated movies for this purpose because there was a possibility that the animation movement might influence the subjects' brain activations.

The percentage of correct responses and the reaction time were analyzed. Reaction time was obtained from video tapes. In each session, children were tested with four cards, each corresponding to a 10-s task period. We measured how long children took to sort each card. Because of experimenter errors, we failed to record the reaction times of two adults and one child, who were consequently excluded from the analyses.

NIRS recordings and analysis

NIRS measurements were performed throughout the experiment. A multichannel NIRS unit operating at wavelengths of 780, 805, and 830 nm (FOIRE-3000; Shimadzu, Kyoto, Japan) was used to measure temporal changes in the concentrations of oxyhemoglobin (oxy-Hb), deoxy-hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb). One NIRS probe included eight optodes that formed 10 channels. A probe was placed on

the primary motor area of each hemisphere. Each channel consisted of one emitter optode and one detector optode located 3 cm apart for adults and 2.5 cm apart for children. The sampling rate at each channel was approximately 10 Hz.

The region of interest (ROI) was located near C3/4 of the International 10/20 system, which corresponds to Brodmann areas (BA) 1/3/6 (Okamoto et al., 2004), because previous studies in infants and adults have shown that these areas are activated during observation of action (Shimada & Hiraki, 2006). The spatial resolution of NIRS is relatively low, and therefore chs 4, 6, 7, and 9; and chs 15, 17, 18, and 20 were defined as corresponding to the left primary motor cortex and the right primary motor cortex, respectively.

In NIRS experiments, quick head movements by participants can cause sharp changes in hemoglobin signals. Test sessions were discarded if motion artifacts were revealed by video recordings and the NIRS data. Approximately 2% of the data for adults and 10% of the data for children were excluded from the analyses. From the three NIRS parameters measured, the concentration of oxyHb was found to be the most sensitive to changes in regional cerebral blood flow, and this provided the strongest correlation with the blood-oxygen-level-dependent (BOLD) signal (Hoshi, Kobayashi, & Tamura, 2001;

Strangman, Culver, Thompson, & Boas, 2002). Thus, we analyzed changes in oxyHb as the best indicator of brain activity. Following previous studies (Moriguchi & Hiraki, 2009; Shimada & Hiraki, 2006), the raw data were converted into Z scores that are calculated using the mean value and the standard deviation of oxy-Hb changes during the resting phase. Consequently, the mean value and standard deviation were changed to Z scores of 0 and 1, respectively, in every channel during both the resting and the control phases. Although the raw NIRS data were originally relative values, and therefore could not be averaged directly across subjects or channels, the Z scores could be averaged regardless of the units.

We analyzed the oxy-Hb changes from 5 to 15 s after the onset of the observation phases, and defined this as the test phase (Figures 2 and 3). This was because hemodynamic responses lag a few seconds behind task onset in infants and young children (Taga, Asakawa, Maki, Konishi, & Koizumi, 2003). The baseline phases were defined as the last 5 s before the onset of the task. We subtracted the changes during the baseline phases from the changes during the observation phases and compared the resulting values between conditions and hemispheres. The average oxy-Hb changes during the observation phases were calculated for all channels in each subject. To reduce the signal-to-noise ratio, we

aggregated chs 4, 6, 7, and 9 into the left primary motor area, and chs 15, 17, 18, and 20 into the right primary motor area.

Results

Behavioral Results

The behavioral results revealed that adults performed almost perfectly under both live and video conditions. Children also performed the tasks quite well (Figure 2A). The percentage of correct responses was analyzed using a mixed repeated-measures ANOVA using participant (children vs. adults) as the between-subjects factor and condition (live vs. video) as the within-subjects factor. A significant main effect of age was found (F [1,23] = 5.047, $p < .04$, $\eta_G^2 = .14$), but no significant main effect of condition or no significant age × condition interaction were found (F [1,23] = 0.016, $p > .10$, $\eta_G^2 = .00$; F [1,23] = 0.016, $p > .10$, $\eta_G^2 = .00$). We then measured the time taken to sort the cards and compared the reaction times in each condition (Figure 2B). A mixed repeated-measures ANOVA was carried out using participant (children vs. adults) as the between-subjects factor and condition (live vs. video) as the within-subjects factor. No significant main effects of age, condition, or no significant age × condition interaction were found (F [1,23] = 0.631, $p > .10$, $\eta_G^2 = .02$; F [1,23] = 2.226, $p > .10$, $\eta_G^2 = .03$; F [1,23] = 0.008, $p > .10$, $\eta_G^2 = .00$).

Thus, no significant behavioral differences were found between live and video demonstrations in either children or adults.

NIRS Results

We measured changes in oxy-Hb in the primary motor areas during the rest and observation phases under live and televised conditions (see Methods), and subtracted the changes during the rest phases from those during the observation phases. Channels were aggregated as described in Methods, as in previous NIRS studies (Matsuda & Hiraki, 2006). Under each condition, the model sorted the cards using the right hand. Thus, it would be expected that participants would recruit the left primary motor regions more strongly than the right motor regions.

In the adult participants, NIRS revealed activation of the primary cortex bilaterally during both live and televised phases (Figure 3). The mean changes in oxy-Hb were analyzed using a two-way repeated-measures ANOVA using laterality (right vs. left) and condition (live vs. video) as the within-subject factors. No significant main effects of laterality, condition, or no significant laterality × condition interaction were found (F [1,14] = 0.472, $p > .10$, $\eta_G^2 = .00$; F [1,14] = 0.029, $p > .10$, $\eta_G^2 = .00$; F [1,14] = 1.006, $p > .10$,

η_G^2 = .00). These results suggest that the primary motor cortex was bilaterally activated similarly under live and video conditions in adults.

In children, the left primary motor cortex showed activation under live conditions, but no such activation was observed in the right primary motor cortex under these conditions. Neither primary region was activated under video conditions (Figure 4). These data were subjected to the same analysis as used with adults, a two-way repeated-measures ANOVA using laterality (right vs. left) and condition (live vs. video) as the within-subject factors. We found no significant main effects of laterality or condition, which was consistent with the results for adults (F [1,13] = 0.530, $p > .10$, η_G^2 = .02; F [1,13] = 0.967, $p > .10$, η_G^2 = .00). However, a significant laterality × condition interaction was found (F [1,13] = 5.571, $p < .04$, η_G^2 = .03). Analyses for a simple main effect revealed that the mean changes in oxy-Hb did not differ in the right primary motor regions across the live and video conditions (F [1,13] = 0.026, $p > .10$, η_G^2 = .00), but the changes were marginally different in the left primary regions across conditions (F [1,13] = 3.441, $p < .09$, η_G^2 = .09). Although the differences in the activations were marginal, a moderate effect size was found. This result revealed that children activated the left primary motor regions relatively more

strongly when learning from live demonstrations than when learning from video demonstrations.

Discussion

The present study provides neuroimaging data demonstrating the neural basis of learning from TV in young children. Both adults and children showed similar behaviors in the live vs. video conditions. This may be because the subjects in the present study were 5- and 6-year-old children. Children of this age can learn rule-based actions from both live and video models, which is consistent with behavioral evidence from studies of the video deficit (Anderson & Pempek, 2005; Troseth & DeLoache, 1998). Nevertheless, at the neural level, children's left primary motor cortex was activated in the live condition but marginally less activated in the video condition.

The results must be interpreted with caution because the differences in the left premotor activations between live and video conditions were only marginal. Nevertheless, the effect size of the differences was moderate. Thus, although the differences in the activations may not be strong, the results in the present study suggest that children's neural processing may be different across the live and video conditions even though the behavioral performances were similar.

The results are consistent with previous neuroimaging evidence that in adults and children, brain regions related to the mirror-neuron system are activated when observing another person's actions (Rizzolatti & Craighero, 2004). Moreover, previous research has shown that the primary motor cortex is activated differently in adults and infants when the subject is passively observing live vs. televised demonstrations (Järveläinen, et al., 2001; Shimada & Hiraki, 2006). However, while previous research examined children's and adults' brain activities when passively viewing another person's actions, the present study demonstrates the neural basis of actively learning from live versus video demonstrations.

Our results revealed that in children, activations in the left primary motor regions were marginally stronger during live demonstrations than during video demonstrations. However, the right primary motor regions did not show any such difference. This laterality effect may be attributable to the fact that the model sorted the cards using her right hand. Based on the results, we suggest that neural processing during our learning task differed at least partially between live and video conditions. In particular, the internal motor representation of the same actions would have been robustly recruited when learning from a live person, but less so when learning from a televised model. Neuroimaging studies in adults showed that televised actions did not recruit mirror regions; rather, they activated the

lateral occipital cortex (Järveläinen, et al., 2001; Perani, et al., 2001). We assume that when learning from video presentations, children may rely more on visual analyses of the card stimuli and activate more occipital regions rather than the mirror neuron system. Thus, it is possible that different neural processing led to similar behavioral performances.

Some limitations of the present study require consideration. First, the tasks used in the present study may be easy for young children. In further research, we should examine whether the same results can be obtained using tasks that are more difficult. Second, other brain regions, in addition to the primary motor areas, may show different activations across live and video conditions. Indeed, adult brain imaging studies have shown that other brain areas, such as lateral occipital cortex, show different activations across conditions (Järveläinen, et al., 2001). Further studies are needed to assess whether other brain regions may be differentially involved in learning from another person under live vs. video conditions.

Conclusion

The present study showed that sensorimotor regions are activated when children learn rule-based actions from a live model, but are less activated when learning from a

televised model. Even though there were no significant behavioral differences across conditions, moderate differences in neural activation were found.

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Figure Legend

Figure 1. Experimental settings. *(A)* Stimuli are presented either live or through a video monitor. *(B)* The NIRS probe is placed into contact with the scalp over the primary motor areas. Each channel (ch) consists of one emitter optode and one detector optode and the regions of interest are located near C3 and C4, which correspond to chs 4, 6, 7, and 9; and to chs 15, 17, 18, and 20 of the probe, respectively.

Figure 2. Behavioral results. *(A)* Percentage of correct responses, and *(B)* mean reaction time, for each age group under live and video conditions. Error bars indicate SE.

Figure 3. Temporal changes in the oxyhemoglobin concentration in the left and right primary motor areas of adult participants. Group mean data under live (blue line) and video (red line) conditions are shown.

Figure 4. Temporal changes in the oxyhemoglobin concentration in the left and right primary motor areas of children. Group mean data under live (blue line) and video (red line) conditions are shown.

Figure 1

A

B

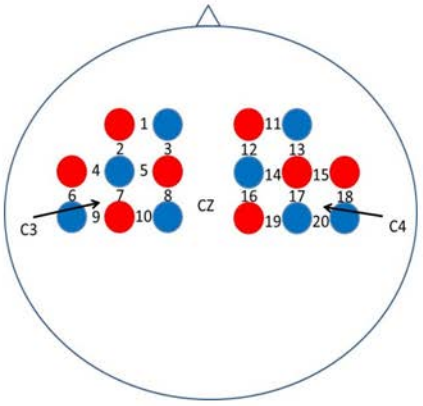


Figure 2

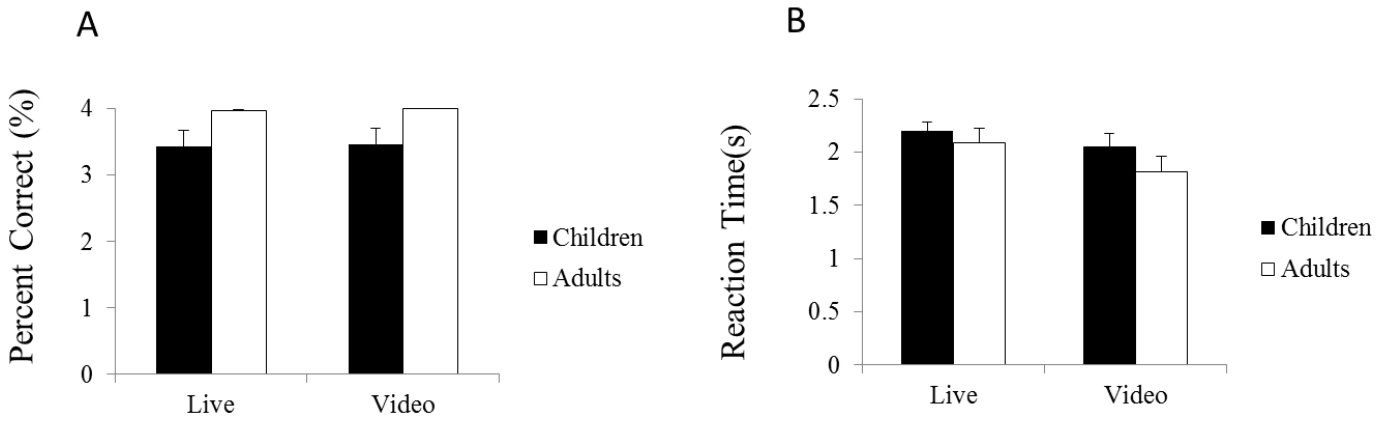

A
Percent Correct (%)
4
3
2
1
0
Live
Video
Children
Adults
B
Reaction Time(s)
2.5
2
1.5
1
0.5
0
Live
Video
Children
Adults

Figure 3

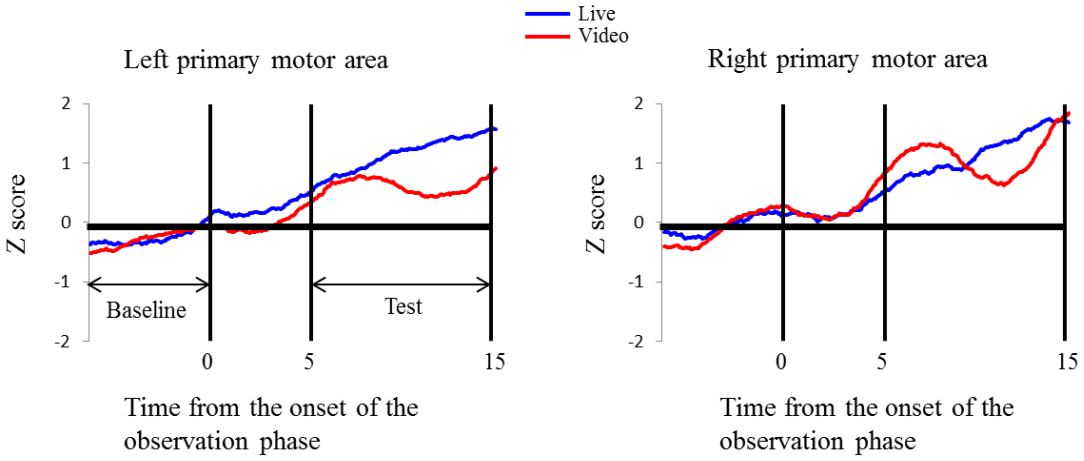
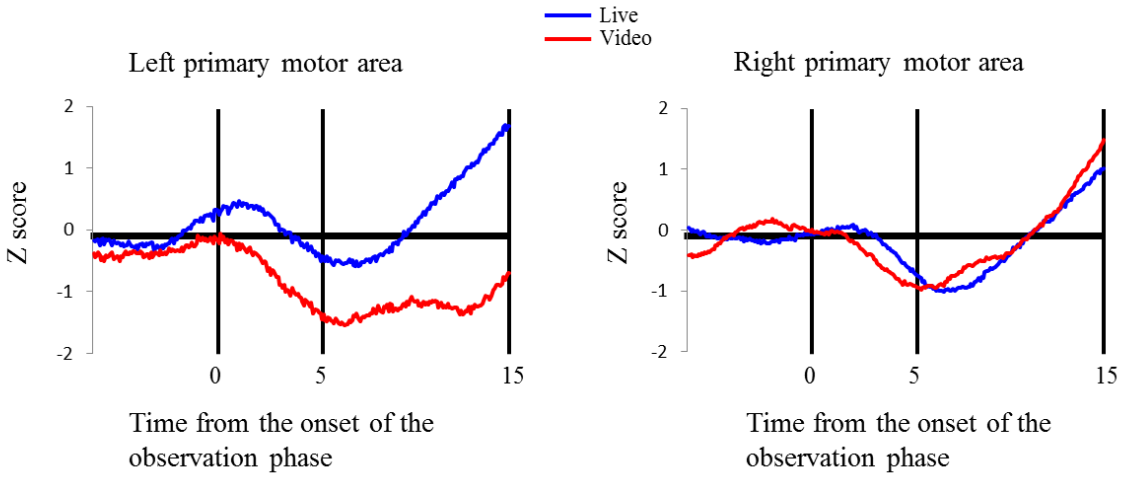

Live
Video
Left primary motor area
Right primary motor area
Z score
2
1
0
-1
-2
Baseline
Test
0
5
15
Time from the onset of the observation phase
Time from the onset of the observation phase

Figure 4


Live
Video
Left primary motor area
Right primary motor area
Z score
2
1
0
-1
-2
0
5
15
Time from the onset of the observation phase