Title: Neural activation to upright and inverted faces in infants measured by
near infrared spectroscopy

Running head: UPRIGHT AND INVERTED FACES IN THE INFANT
BRAIN

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Abstract

The present study examined infants' brain activity in response to upright and inverted faces using near infrared spectroscopy (NIRS), which can non-invasively record hemodynamic changes of the brain. NIRS is particularly useful for recording in infants, since recordings can be made, even while the infants are awake, without fixing their body and brain. For this objective, we used newly developed sensor probes of NIRS for recording in infants. We measured changes in cerebral oxygenation in ten 5-8-month-olds' left and right lateral areas while they were looking at upright and inverted faces. The results are summarized as follows: (1) the concentration of oxyhemoglobin (oxy-Hb) and total-hemoglobin (total-Hb) increased significantly in the right lateral area during the upright face condition, (2) the concentration of total-Hb in the right lateral area differed significantly between the upright and inverted conditions, (3) hemodynamic changes were maximal in the temporal region, probably in the superior temporal sulcus (STS) in both hemispheres, and (4) the right hemisphere seems to be more important for recognizing upright faces. This

is the first evidence showing that there is an inter-hemispheric difference on the effect of face inversion in the infant brain using a hemodynamic method.

Introduction

Recognition of inverted faces is surprisingly poor compared to upright faces. In a seminal article, Yin (1969) reported that the effect of inversion is larger for the recognition of faces than for the recognition of objects: the effect widely known as the face-inversion effect. Since then, the inversion effect on face recognition has been consistently reported by many other studies (for review see, Valentine, 1988). The recognition advantage for upright faces has been attributed to ‘expertise’ with a homogenous class of stimuli seen in one orientation in everyday life (Valentine, 1988; Diamond and Carey, 1986). While the effect of face inversion continues to develop into childhood (Mondloch et al., 2002; Carey and Diamond, 1994), this effect exists even in infancy.

Turati et al. (2004) demonstrated that 4-month-olds process faces differently when the faces are upright as opposed to when they are inverted. Infants recognized upright faces better than inverted faces when faces were shown in a variety of poses, and when the infants were required to recognize a new pose of the same face. Furthermore, Bhatt et al. (2005)

showed that 5-month-olds could detect changes in the spacing between the eyes when a face was shown upright but not when it was inverted. Consistent with these studies, event-related potential (ERP) by averaging electroencephalogram (EEG) showed that cortical activation differs between upright and inverted faces (de Haan et al., 2002; Halit et al., 2003), even though the responses differed from that of adults in the latency and stimulus specificity. These studies recorded ERPs in 3-, 6-, 12-month-old infants and in adults, while they viewed upright and inverted human and monkey faces. de Haan et al. (2002) found that a face sensitive ERP component in adults (N170) showed a sensitivity to facial inversion only for the human faces. In a follow-up study, Halit et al. (2003) further found similar stimulus specificity of the face sensitive component (N290 and P400 in the case with infants) develops by 12-months of age. Although P400 was sensitive to facial inversion even in 6-month-olds, this component did not show sensitivity to the species of faces at 6-months of age (de Haan et al., 2002).

By using near infrared spectroscopy (NIRS), we further examined the neural basis of the effect of face inversion in infancy. NIRS is a non-invasive neuroimaging method that measures changes in the oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb), and total-hemoglobin (total-Hb) concentrations (Villringer and Chance, 1997; Hoshi et al., 2001). The greatest advantage of NIRS compared with functional magnetic resonance imaging (fMRI) is that recordings can be made without having to fix the subjects' body and brain in the apparatus. This is particularly useful for recording with infants awake. Previous studies with infants successfully showed that NIRS can detect not only responses to the simple sensory stimuli (Meek et al., 1998; Sakatani et al., 1999; Bartocci et al., 2000), but also differential cortical activation induced by various visual patterns (Taga et al., 2003), objects (Wilcox et al., 2005), and speech (Pena et al., 2003).

Recently, Csibra et al. (2004) further demonstrated that NIRS can detect differences in the processing induced by face and non-face stimuli equated in terms of low-level sensory properties of spatial

frequency and color distributions. However, in that study, it was difficult to investigate the results in detail, since they recorded with NIRS using only two channels.

In the present study, we measured changes in cerebral oxygenation in 5-8-month-olds while they were looking at upright and inverted faces (Figure 1a). The hemodynamic responses to the upright and inverted faces were contrasted with the hemodynamic response to the presentation of objects (Figure 1b) as a control (baseline). Behavioral studies have demonstrated the effect of face inversion in infants at around 4- to 5-months of age (Turati, et al. 2004; Bhatt, et al., 2005). Thus, we hypothesized that a differential brain response would be found for upright and inverted faces in infants over 5-months of age. As several previous studies have indicated that there is some inter-hemispheric asymmetry in infant face recognition (de Schonen and Mathivet, 1990; de Haan and Nelson, 1997; de Haan and Nelson, 1999), we decided to measure the hemodynamic responses from both the left and right lateral areas (Figure 1c). For this objective, using newly developed probes for recording in

infants, which were designed with many sensors (Hitachi Medical, Infant probe 3×3 mode: Figure 1d). This is the first systematic and detailed study to examine face recognition by viewing upright and inverted faces in awake infants. We found an inter-hemispheric difference on the effect of face inversion in the infant brain.

Methods

Participants

The participants were 10 healthy infants aged 5- to 8-months (3 girls and 7 boys, mean age 186.2 days). An additional 10 infants had their data excluded due to few available trials (less than 6 trials for either the upright or inverted condition), because of crying, not looking at the stimuli, or motion artifacts. One infant's data was excluded because optimal condition for the measurement could not be achieved due to hair interference (less than 20 intact channels). This study was approved by the Ethical Committee of the National Institute for Physiological Sciences, and written informed consent was obtained from the parents of the infant

participants. The experiments were conducted according to the Declaration of Helsinki.

Stimuli

The face stimuli were color images of 5 female faces (Figure 1a), and the object stimuli were color images of 5 vegetables (Figure 1b). The sizes of the stimuli were approximately $17.5 \text{ deg} \times 21 \text{ deg}$ for the faces, and $16.8 \text{ deg} \times 16.8 \text{ deg}$ for the objects.

In each trial, 5 faces were shown in a random order at a rate of 1 Hz. The faces were shown upright in half of the trials, and inverted in the other half of the trials. The upright and inverted face stimuli were presented at alternating trials. The order of the presentation was counterbalanced across infants. The duration of the trials was fixed for 5 seconds. During the inter-trial intervals, 5 objects were shown in a random order at a rate of 1 Hz. The inter-trial interval was controlled by the experimenter, and its duration was at least 10 seconds. The results obtained by viewing objects were used as a control (baseline).

For both the face and object stimuli, the stimulus duration was 800 milliseconds, and the 200 milliseconds inter-stimulus interval was filled by the presentation of a small red cross. Both the face stimuli and object stimuli were accompanied by a beeping sound presented at 1 Hz. Two different sounds were used for the face stimuli and object stimuli, but they were the same between the upright and inverted faces. The relationship between the sounds and visual stimuli were counterbalanced across infants.

Procedure

The infants watched the stimuli passively while they were seated on one experimenter's lap. The viewing distance was approximately 40 cm. The infants were allowed to watch the stimuli as long as they were willing to. Their behavior was videotaped throughout the experiment.

Recording

A commercially available Hitachi ETG-100 system was used to record simultaneously from 24 channels. This instrument generated two wavelengths of NIR (780 and 830 nm) and measured time courses of the

levels of oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb), and their sum (total hemoglobin: total-Hb) at 24 channels with 0.1-s time resolution. Since we used newly developed sensor probes of NIRS (Hitachi Medical, Infant probe 3×3 mode: Figure 1d) for recording in infants, which had a lower weight than the previous probe and made softer contact with the skin, it was observed that most of the infants appeared to enjoy the experiments, and did not show reluctance to participate.

We used a pair of probes, each consisting of 3×3 arrays with five emitting and four detecting fibers (Figure 1c). The optical fibers of each probe were kept in place with a soft silicon holder. The distance between the emitting and detecting fibers was set at 2 cm. Each pair of adjacent emitting and detecting fibers defined a single measurement channel, which allowed the measurement of oxy-Hb and deoxy-Hb changes at 12 channels for each measurement area. The probes were placed on the lateral region of each hemisphere, including T3 and T4 (international 10/20 system for recording EEG) in the inferior portion (see Figure 2c). Although a more posterior region might also be important for human face perception,

it was difficult to set and keep the probe position in a more posterior region due to a technical problem. The surface of the skull is relatively flatter in this anterior region, but rounded in the more posterior region. The rounded configuration of the skull in the posterior region makes it difficult to obtain an optimal fit of the probe on the infants' skulls. We thus selected this anterior region (T3 and T4) as the measurement site, because the flatter configuration of the skull made it possible to obtain an optimal fit between the probe and infant skull necessary for a stable measurement.

When the probes were positioned, the experimenter checked to see if the fibers were touching each infant's scalp correctly. The Hitachi ETG-100 system automatically detects whether the contact is adequate to measure emerging photons for each channel. The channels were rejected from the analysis if the adequate contact between the fibers and each infant's scalp could not be achieved because of interference by hair.

Data analysis

Given the wavelengths used by the ETG-100 model (780 and 830 nm), the oxy-Hb and total-Hb estimations are more precise than the

estimation of deoxy-Hb (Pena et al., 2003). Therefore, our analysis focused on the variation of oxy-Hb and total-Hb.

Based on the video recordings, we coded the infants' behavior during the experiment. The coders noted in the trials if infants looked away from the stimuli or became fussy. The infants were held on the experimenter's lap, and the coders also noted if the infants looked back at the face of the experimenter during the preceding baseline period. These trials were rejected from further analysis. We further removed the trials that included movement artifacts, which were detected by the analysis of sharp changes in the time series of the raw data of the NIRS. The raw data of oxy-Hb and total-Hb from individual channels were digitally high-pass-filtered at 0.02 Hz to remove any longitudinal signal drift (Taga et al., 2003). Then the mean concentration of each channel within a subject was calculated by averaging data across the trials in a time series of 0.1sec time resolution from 1 sec before trial onset to 1 sec after trial offset.

Based on the mean concentrations in the time series, we calculated the Z-scores of oxy-Hb and total-Hb in the upright and inverted

face condition for each channel within a subject. The Z-scores were calculated as the difference of the means of the baseline and trial divided by the standard deviation of the baseline:

$$d = (m1 - m2)/s.$$

Accordingly, “m1” and “m2” are the mean concentration values during the baseline and trial and “s” is the standard deviation of the baseline. The mean concentration value of 1 second immediately before trial was used as a baseline. Then the Z-scores obtained from 12 channels within each measurement area were averaged in order to increase the signal-to-noise ratio. Although the raw data of NIRS were originally relative values, and could not be averaged directly across subjects or channels, the normalized data such as the z-scores could be averaged regardless of a unit (Matsuda & Hiraki, 2006; Shimada & Hiraki, in press; Schroeter et al., 2004).

Previous studies showed that the hemodynamic response typically lags behind the stimulation for a few seconds, and peaks around 8 to 10 s after stimulus presentation in infants (Meek et al., 1998; Sakatani et

al., 1999; Bartocci et al., 2000; Taga et al., 2003; Csibra et al., 2004).

Therefore, the hemodynamic response would reach a peak after the end of the 5-seconds-long trials. However, when we measured the hemodynamic response for a longer period in a pilot study, the data obtained subsequent to the trial period were very noisy due to the head movements of the infants, and were thus not suitable for analysis. In fact, we observed that many infants in many trials looked away from the CRT monitor immediately after trial offset, and then within a few seconds looked at the monitor again. Based on this observation, we determined to make statistical analyses against the mean Z-scores of the last 1 second of the trials in order to avoid data including motion artifacts.

Results

Data were obtained from ten infants who stationary looked at the stimuli in more than 5 trials in both the upright and inverted face conditions. The mean number of trials was 9.4 for the upright condition and 8.7 for the inverted condition, and the mean number of channels was 11.8 for the left lateral area and 11.7 for the right lateral area.

Figure 2 shows the time course of the average change of the oxy-Hb and total-Hb concentrations during the presentation of the upright and inverted faces. Graphs a-d show the average change of oxy-Hb, and graphs e-h shows those of total-Hb. The grand-averaged data of all probes obtained by all ten subjects in each hemisphere are shown to demonstrate the general tendency of inter-hemispheric difference. The graphs in the left column show data from the left lateral area (1-12 channels), and those in the right column show data from the right lateral area (13-24 channels). The thick line in the graphs represents the mean Z-score, and the thin line represents 1 standard error (SE). The vertical dashed lines in the graphs represent the start and end of facial presentation. The concentrations of both oxy-Hb and total-Hb in the right lateral area (Figures 2b and 2f) increased during the presentation of upright faces. This increase occurred at about three seconds after the onset of the facial presentation. By contrast, the increase in the concentration was not observed during the presentation of inverted faces (Figures 2d and 2h). Unlike the right lateral area, the

concentrations in the left lateral area showed a similar tendency between the upright (Figures 2a and 2e) and inverted (Figures 2c and 2g) conditions.

Tables 1 and 2 show the channels activated compared to the object baseline during 1 second of the 5 seconds-long presentation of the upright and inverted face stimuli, respectively. During the upright face condition (Table 1), the inferior region being maximal around the T3 position showed a significant Z-score in the left hemisphere. By contrast, in the right hemisphere, wider regions showed a significant Z-score compared with the left hemisphere, but the Z-score was maximal around the T4 position. The same tendency was identified during the inverted face condition (Table 2), but the following two points were different from the results during the upright face condition. (1) Wider region showed a significant increase of Z-score in the left hemisphere, and (2) the total-Hb showed a significant decrease of the Z-score in the middle region in the right hemisphere. That is, each hemisphere showed a reversed change for upright and inverted faces.

Figure 3 shows the mean Z-score during the last 1 second of the trials in the left and right lateral area. A two tailed one-sample *t*-test vs. a chance level of 0 revealed that the concentration of both oxy-Hb and total-Hb increased significantly in the right lateral area during the upright face condition (oxy-Hb: $t(9)=3.67, p < .01$; total-Hb: $t(9) = 4.68, p < .01$). Furthermore, a two tailed paired *t*-test showed that the concentration of total-Hb in the right lateral area was significantly higher during the upright than during the inverted condition ($t(9) = 2.46, p < .05$). A repeated-measure *ANOVA* with two factors: condition (upright versus inverted) and measurement area (right versus left) on the data of oxy-Hb and total-Hb was separately performed. This analysis revealed a marginally significant effect of condition for total-Hb ($F(1, 9) = 4.28, p = .068$). The effect of measurement area and interaction was not significant. In addition, no significant effect or interaction was found for oxy-Hb.

Discussion

The present study provided further evidence that several months of experience can lead to induce some effect of face inversion.

Compared to the presentation of the objects, the presentation of the upright, but not inverted faces induced an increase in the concentration of oxy-Hb and total-Hb in the right lateral area of the infant brain. By contrast, no such hemodynamic response was observed in the left lateral area. Our findings indicate that (1) neural signals to faces differ from that to objects in the infant brain, and that (2) this difference in the neural signals is greater for upright faces than for inverted faces in the right hemisphere, but not in the left hemisphere, in the infant brain.

Previous behavioral studies demonstrated that infants as well as adults show better recognition of faces when they are shown in an upright rather than inverted orientation (Turati et al., 2004; Bhatt et al., 2005). In addition, an ERP study showed that cortical activation differs between upright and inverted faces (de Haan et al., 2002; Halit et al., 2003). In the present study, we further found that the hemodynamic response to upright faces differ from that to objects, while that of inverted faces does not. These findings suggest that several months of experience can lead to

induce some effect of face inversion in infants, although it takes years of experience to become adult like (Mondloch et al, 2002; 2003).

Interestingly, the differential response to upright and inverted faces was not found in the left lateral area. The observed asymmetry between the right and left hemisphere is consistent with the asymmetry observed in previous studies, which shows the greater involvement of the right than the left hemisphere in the recognition of faces. To date, right hemisphere dominance for the processing of faces has been consistently reported by lesion studies (e.g., Sargent & Signoret, 1992 ; Bouvier & Engel, 2006), neuroimaging (e.g. Sargent et al., 1992 ; Kanwisher et al., 1997 ; McCarthy et al., 1997), and event-related potential studies (e.g. Rossion et al., 2003) in adults. A similar right hemisphere advantage has also been reported in developmental studies on infants. Using a divided visual field presentation procedure, de Schonen & Mathivet (1990) showed that infants learned discrimination of faces more rapidly if the faces were shown to the right hemisphere (left visual field) than to the left hemisphere (right visual field). In the ERP study, de Haan & Nelson (1997; 1999)

reported a greater difference in neural activity in the right than the left hemisphere for the discrimination of faces, but not for the discrimination of objects.

The right hemisphere dominance for processing of upright faces found in the present study would be related to some ability of infants to process configural information of faces. Although the ability to process configural information of faces does not become adult-like even in childhood (Mondloch et al., 2002 ; 2003), there is some evidence that infants can process configural information of faces. Bhatt et al., (2005) showed that 5-month-olds discriminated faces that differed only in the spacing between eyes when the faces were upright but not when they were inverted. This finding suggests that infants can process configural information of faces only when the faces are upright. Using the divided visual field presentation procedure, Deruelle & de Schonen (1998) found that 4- to 10-month-olds show a right hemisphere advantage for the processing of configural or relational information of upright faces. In addition, the infants showed a left hemisphere advantage for the processing

of facial features. Furthermore, Le Grand et al. (2003) suggested that there was some inter-hemispheric difference in the processing of upright faces but not that of inverted faces. Le Grand et al. (2003) examined the face processing skills of patients who had been treated for congenital cataracts either in the left or right eye. The deprivation to either eye was thought to block visual input mainly to the contralateral hemisphere. They found that early deprivation just to the left eye (right hemisphere) was sufficient to cause a deficit in the processing of faces. Importantly, the deficit caused by the early visual deprivation was prominent when the task demanded processing of configural information of the faces. Furthermore, the deficit was shown in the processing of upright faces but not in the processing of inverted faces. These results suggest that the right hemisphere plays an important role in the development of expertise in the processing of upright faces.

Using NIRS with newly developed multi channel sensor probes, we extended their finding by showing that the right hemisphere but not the left hemisphere of the infant brain show differential

activation to upright and inverted faces. The present study has provided the first evidence that there is inter-hemispheric difference in the effect of face inversion in the infant brain.

With regards to studies with adult participants, behavioral and neurophysiological studies using divided hemi-field stimulation have provided evidences of the right hemisphere advantage for processing upright but not inverted faces. In a behavioral study, Hillger & Koenig (1991) found the right hemisphere advantage for processing upright faces, but not when configural analysis of the faces was disrupted by face inversion. Hillger & Koenig (1991) also found a left hemisphere advantage for the detection of featural changes of faces. Similar findings were obtained from ERP and MEG (McCarthy et al., 1999; Watanabe et al., 2003) showing that the latency of neural activity in the right hemisphere was shorter for upright faces than for inverted faces, while the opposite pattern was observed in the left hemisphere. These studies suggest the important role of the right hemisphere for the processing of upright faces, and the left hemisphere for the processing of inverted faces.

Unlike the studies using divided hemi-field stimulation, however, most of the other neuroimaging studies employing centrally presented stimuli did not find a hemispheric difference on the effect of face inversion in human adults (e.g. Bentin et al., 1996; Haxby et al., 1999; Rossion et al., 2000; Mazard et al., 2006; for review see Rossion & Gauthier 2002; but see Yovel & Kanwisher, 2004). Similarly, previous developmental studies recording ERP found a bilateral effect of face inversion in infants (de Haan et al., 2002; Halit et al., 2003). Taken together, these previous studies suggest that the hemispheric asymmetry on the effect of face inversion is weaker when stimuli are shown centrally than when they are shown hemi-field.

Using centrally presented stimuli, we found some hemispheric asymmetry on the effect of face inversion in infants. Our results do not necessarily contradict with the previous studies which found no hemispheric difference in the effect of face inversion. Although we found differential neural activity to upright and inverted faces only in the right hemisphere, the hemispheric difference in the inversion effect was not

strong enough to induce significant interaction between the measurement areas and facial orientations. This is consistent with the notion that the hemispheric asymmetry in the effect of face inversion is weak when stimuli are shown centrally.

It is very difficult for NIRS to detect the activated regions in detail compared with fMRI, since NIRS can detect activities only in a very superficial layer of the cortex due to its technical limitation. NIRS can detect hemodynamic changes mostly in areas 2–3 cm below the scalp (Chance et al., 1993). Therefore, NIRS probably cannot detect activity in the fusiform gyrus, which is considered to be one of the most important regions for face perception, although the infant brain is much smaller than the adult brain. However, NIRS is able to detect activities in the superior temporal sulcus (STS) and human homologue MT/V5 regions, which are also considered to be important regions for face perception (Watanabe et al., 2001, 2003; Puce et al., 1998). Regions showing significantly large Z-scores in the present study appear to reflect activities in STS. By using fMRI, Yovel & Kanwisher (2005) reported that STS may play some role in

the effect of face inversion. Their results showed that bilateral face-sensitive regions in both the fusiform gyrus and STS, but not in the occipital area, showed a higher neural response to upright than inverted faces. Our findings seem compatible with their results, and we can speculate that such effect is taking place in the right STS of infants.

In a previous neuroimaging study using PET, Tzourio-Mazoyer et al. (2002) reported right hemisphere dominance for faces in posterior areas in infants as young as 2 months old. They found that faces activated a distributed network of cortical areas, including the fusiform gyrus and inferior occipital area, which is compatible with the face-sensitive areas in adults. However, Tzourio-Mazoyer et al. (2002) did not find activation in STS. These results and ours indicate that STS becomes functional some time between 2-months and 5-months of age. Considering that the infants in Tzourio-Mazoyer et al. (2002) suffered from major brain stress at birth, caution is needed when interpreting the observed difference between the studies. Because of methodological and ethical reasons, however, it is not suitable to use PET for healthy human infants while they

are awake. Further study using NIRS with healthy infants will reveal the more precise developmental course of the neural basis for face processing during infancy.

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Figure Legends

Figure 1. (a and b) Examples of the face and object stimuli used in the experiment. (c) Location of the optical fibers placed on the lateral areas in both hemispheres. The distance between the fibers was set at 2 cm. T3 and T4 was located at the center between channels 11 and 12, and 23 and 24, respectively. (d) An infant wearing the newly developed sensor probes of the NIRS (Hitachi Medical, Infant probe 3×3 mode) for recording in infants.

Figure 2. The time course of the average change of the oxy-Hb (a - d) and total-Hb (e - h) concentrations during the presentation of upright faces (a, b, e, and f) and inverted faces (c, d, g, and h). The left column shows data from the left lateral area, and the right column shows those from the right lateral areas. The thick line in the graphs represents the mean Z-score, and the thin line represents 1 standard error (SE). The vertical dashed lines in the graphs represent the start and end of facial presentation. In the right lateral area, the concentrations of both oxy-Hb and total-Hb increased

during the presentation of upright faces (b and f), but not during the presentation of inverted faces (d and h). No such difference was observed in the left lateral area (a, c, e, and g).

Figure 3. Mean Z-score during the last 1 second of the trials in the left (a) and right (b) lateral areas. The vertical bar in the graphs represents 1 standard error (SE). The concentration of both oxy-Hb and total-Hb in the right lateral area was significantly greater than the chance level of 0 in the upright face condition ($p < .01$). Moreover, the concentration of total-Hb in the right lateral area differed significantly between the upright and inverted conditions ($p < .05$).

Table 1
Channels activated in the upright face condition compared to the baseline

		oxy-Hb		total-Hb	
	ch	mean	Z-score	ch	mean Z-score
left	12	3.08	***	8	0.82 *
				9	3.93 ***
				11	4.61 ***
				12	4.84 ***
right	15	1.36	*	13	3.12 ***
	21	1.99	***	14	2.72 ***
	23	4.10	*	15	2.08 ***
	24	3.82	***	21	1.61 ***
				22	1.49 **
				23	4.48 ***
				24	4.35 ***

* $p < .05$, ** $p < .01$, *** $p < .001$: two-tailed one sample t -test vs. chance level of 0.

Table 2

Channels activated in the inverted face condition compared to the baseline

	oxy-Hb			total-Hb		
	ch	mean	Z-score	ch	mean	Z-score
left	12	2.99	*	5	-1.22	*
				6	2.45	**
				7	3.23	**
				9	4.34	***
				12	3.61	***
right	24	2.40	*	15	-1.40	**
				17	0.53	**
				18	-1.42	**
				19	-1.54	**
				21	2.06	**
				23	4.34	***
				24	3.03	***

* $p < .05$, ** $p < .01$, *** $p < .001$: two-tailed one sample t -test vs. chance level of 0.

d

Figure 2

Upright face

Inverted face

Upright face

Inverted face

Figure 3