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# Natural, but not artificial, facial movements elicit the left visual field bias in infant face scanning

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ABSTRACT

A left visual field (LVF) bias has been consistently reported in eye movement patterns when adults look at face stimuli, which reflects hemispheric lateralization of face processing and eye movements. However, the emergence of the LVF attentional bias in infancy is less clear. The present study investigated the emergence and development of the LVF attentional bias in infants from 3 to 9 months of age with moving face stimuli. We specifically examined the naturalness of facial movements in infants' LVF attentional bias by comparing eye movement patterns in naturally and artificially moving faces. Results showed that 3- to 5-month-olds exhibited the LVF attentional bias only in the lower half of naturally moving faces, but not in artificially moving faces. Six- to 9-month-olds showed the LVF attentional bias in both the lower and upper face halves only in naturally moving, but not in artificially moving faces. These results suggest that the LVF attentional bias for face processing may emerge around 3 months of age and is driven by natural facial movements. The LVF attentional bias reflects the role of natural face experience in real life situations that may drive the development of hemispheric lateralization of face processing in infancy.



## 1. Introduction

Faces are likely the most frequently encountered visual stimuli in our everyday experience. One common characteristic that faces share is that they are nearly symmetrical along the horizontal axis: the eyes are on either side of the face with the nose and mouth in the middle. However, the way we process faces has long been found to be asymmetrical. We tend to rely on the left side of the face (from the perceiver's perspective) more than the right side in face processing. This left visual field (LVF) bias has been consistently found in the literature with children and adults and has been linked to the hemispheric lateralization of face processing (Gilbert & Baken, 1973; Yovel, Tambini, & Brandman, 2008). However, little research has examined the emergence and development of the LVF face bias in infancy. To address this important gap in the literature, the present study, using eye tracking, investigated (1) whether infants as young as 3 months of age already display a LVF bias, and (2) how this bias emerges and develops with increased age in the first year of life.

Investigations of the left visual field bias in face processing were inspired by the observations of Wolff (1933). In his study, Wolff (1933) reported that the left and right face halves were different in their emotional expression resemblance to the whole face. Participants consistently judged emotion on the left face half (from the observer's view) as closer to the whole face's emotion than that on the right face half. In addition to face emotionality, this *LVF perceptual bias*, which biases perception to the face half in the left visual field, has been consistently observed in terms of face recognition, emotion categorization, and age judgment (Aljuhanay, Milne, Burt, & Pascalis, 2010; Burt & Perrett, 1997; Butler & Harvey, 2008; Chiang, Ballantyne, & Trauner, 2000; Coolican, Eskes, McMullen, & Lecky, 2008; Dahl, Rasch, Tomonaga, & Adachi, 2013; Gilbert & Bakan, 1973; Levine & Koch-Weser, 1982; Levine, Banich, & Koch-Weser, 1984, 1988; Levy, Heller, Banich, & Burton, 1983; Levy, Trevarthen, & Sperry, 1972; Luh, Redl, & Levy, 1994; Luh, Rueckert, & Levy, 1991; Sackeim & Gur, 1978; Yovel et al., 2008). Gilbert and Baken (1973) proposed that the LVF perceptual bias is likely due to right hemispheric dominance for face processing. Face information in the left visual field is projected to the contralateral right hemisphere, leading face perception to be disproportionally reliant on the left face half. This proposal has recently been supported by a neural imaging study, which found a positive association between the face selective region activation in

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the right hemisphere and the size of the LVF perceptual bias (Yovel et al., 2008).

Recent studies using eye-tracking technology observed that the LVF perceptual bias was linked to a leftward eye movement pattern in face processing (Butler et al., 2005; Butler & Harvey, 2006; Dundas, Best, Minshew, & Strauss, 2012; Dundas, Gastgeb, & Strauss, 2012; Guo, Smith, Powell, & Nicholls, 2012; Hsiao & Cottrell, 2008, 2009; Mertens, Siegmund, & Grüsser, 1993; Schyns, Bonnar, & Gosselin, 2002). Butler et al. (2005), for example, observed that participants who relied on the left face half for judgment of face gender exhibited significantly longer looking time on the left face half and an initial leftward saccade to the left visual field. By contrast, no such leftward saccade or looking time preference was observed for those who did not show the LVF bias. Butler and Harvey (2006) further suggested the crucial role of eye movements in the LVF perceptual bias by showing a significant decrease in the LVF bias when eye movements were restricted. This leftward eye movement bias was named *the LVF attentional bias*, which stands for the accumulatively longer looking time or initial leftward saccade for the face half in the left visual field. Based on the findings from Butler and co-workers, researchers regarded the LVF attentional bias, similar to the LVF perceptual bias, as rooted in right hemispheric dominance for face processing. The stronger activation in the right hemisphere face network can be transmitted to the frontal eye fields (FEF, BA45, and BA8) in the right hemisphere through the neural connections between the two (Bullier, Schall, & Morel, 1996; Schall, Morel, King, & Bullier, 1995). The FEF is the neural region that mainly controls eye movement to the contralateral side; the activation in the right FEF would lead to eye movement to the left side (Robinson, 1968). Thus, the lateralized activation in the right hemisphere during face processing would result in the LVF attentional bias.

Several lines of research have supported the proposed involvement of the right hemisphere in the LVF attentional bias. The first focused on the specificity of the leftward eye movement pattern for face processing. Leonards and Scott-Samuel (2005) reported an initial saccade to the left visual field in adult participants only for upright face stimuli but not for inverted faces, landscapes, or patterns. In line with this finding (Guo, Meints, Hall, Hall, & Mills, 2009) observed such face specificity in terms of longer looking time on the left face half in adults. These studies reflect the underlying role of the right hemispheric lateralized face selective neural network, which is shaped by long-term face experience (Birmingham et al. 2012). The second line of studies for the LVF attentional bias mainly compared the face-scanning pattern in a typically developing population to that in individuals with autism spectrum disorder (ASD). Individuals with ASD have been found to have difficulties in processing face stimuli, which is probably due to their lack of right hemisphere lateralization for face processing (Ashwin, Wheelwright, & Baron-Cohen, 2005). One would expect lack of lateralization to restrict eye movements to the left visual field. Consistent with this proposal, Dundas and Best (2012) found that typically developed adults and adolescents exhibited longer looking time to the left side of the face, while no such LVF attentional bias was observed in observers with ASD. In sum, both behavioral and neuropsychological studies have supported the association between the LVF attentional bias and the right hemisphere lateralized face processing neural network in children, adolescents, and adults.

In contrast to the consistent LVF attentional bias found in children, adolescents, and adults, little is known about the emergence and development of the LVF attentional bias in the first year of life. Dundas and Gastgeb (2012) observed that 11-month-olds looked longer on the left than the right side of face, while no such bias was revealed in 6-month-olds or in infants with high ASD risk. This study suggested that the LVF attentional bias in face processing might emerge between 6 and 11 months of age. Another study reported the LVF attentional bias in 6-month-olds (Guo et al., 2009). The LVF attentional bias found in this study was not face specific. It was found with not only upright human faces, but also inverted human faces, upright and inverted monkey faces, and objects. When considering all these findings, it seems the face specific LVF attentional bias emerges at around 11 months of age, although a more general LVF attentional bias can be revealed as early as 6 months.

However, it should be noted that this developmental trajectory of the LVF attentional bias is inconsistent with findings that the specialization of the right hemisphere for face processing emerges around 4 months after birth (Deruelle & de Schonen, 1998; de Schonen & Mathivet, 1990). The findings consistent with an earlier emergence have been further supported by recent neural imaging studies using event-related potential (ERP) and functional near infrared spectroscopy (fNIRS) technology (Honda et al. 2010; Ichikawa, Kanazawa, Yamaguchi, & Kakigi, 2010; Nakato et al. 2009; Otsuka et al. 2007; Scott, 2006). Considering the association between the LVF attentional bias and the lateralized face processing neural network, the LVF attentional bias would be expected to emerge even earlier in infancy. But to the best of our knowledge, few studies have reported a LVF attentional bias under 6 months of age.

It is notable that most of the studies investigating infants' LVF attentional bias used static face pictures as stimuli. However, in real life situations, most faces that young infants see are moving ones: they smile, talk, chew, and change viewpoints. The richness of facial movement information has been found to lead to more right hemispheric activity than static faces (Ichikawa et al., 2010; Pitcher, Dilks, Saxe, Triantafyllou, & Kanwisher, 2011; Schultz, Brockhaus, Bülthoff, & Pilz, 2013). Ichikawa et al. (2010), for example, used fNIRS to examine 7- to 8-month-olds' neural response to abstract point-light moving face stimuli. Relative to a static point-light display, facial movement induced more neural activity in the right temporal region. If moving faces activate stronger right hemispheric neural activity than static faces in infants, we would expect to observe the associated leftward eye movement in early infancy, which may not be observed with static faces as stimuli. Consistent with this proposal, a recent study found a LVF attentional bias in 4- to 9-months-olds (Liu et al., 2011). It used more natural dynamic faces as stimuli and presented 4- to 9-month-olds with frontal-view silent videos that depicted a woman counting. The results demonstrated that infants looked marginally longer at the face half to the left of the vertical midline than at the face half to the right of the midline. Compared to those studies that used static face pictures as stimuli (Dundas et al. 2012b; Guo et al., 2009), the Liu et al. (2011) results suggest that the introduction of facial movement might facilitate leftward eye movement. Based on these previous studies, the present study examined the role of facial movement in the emergence and development of the LVF attentional bias for face processing in infants between 3 and 9 months of age.

Although previous studies have shown that facial movements can activate a right lateralized neural response, it should be noted that the findings were derived from the contrast between moving and static faces. We do not know to what extent the right hemispheric activation reflects the role of facial movement as opposed to other motion-related attributes. Facial movement would directly lead to changes in the spatial relations among facial features (e.g., eyes, nose, and mouth), which is referred to as configural information (Maurer, Le Grand, & Mondloch, 2002). Earlier studies have shown that the processing of facial configural information was also dominant in the right hemisphere in infancy (Deruelle & de Schonen, 1998; Scott, 2006). These findings suggest that the link between facial movement and the LVF attentional bias could actually have been mediated by the amplified facial configuration processing, which is not directly related to facial movement. In order to specifically examine whether natural facial movement actually contributes to the LVF attentional bias in infancy, we compared infants' eye movement patterns while watching a naturally moving face and an artificially moving face. The naturally moving face depicted a female model counting numbers. The artificially moving face was a mirrored version of the naturally moving face that was created by flipping the natural video horizontally, which had identical image information to the naturally moving face. Flipping creates a face moving in an unnatural pattern due to the fact that the facial movement during speech is asymmetrical as a result of the left-lateralized control of speech-related facial muscle movements (Chaurasia & Goswami, 1975; Wildgruber, Ackermann, Klose, Kardatzki, & Grodd, 1996). Infants should be familiar with the facial movements presented in a natural way. In contrast, they should have little experience with the flipped facial movements, which might be unnatural to them. Comparing these two types of facial movements could help us to specify the role of natural facial movement in the development of the LVF attentional bias by ruling out other non-movement factors, such as changes in facial configuration.

We showed each infant participant two silent videos. If natural facial movement can activate the LVF attentional bias, we expected the LVF attentional bias to occur only in the naturally moving face condition, while no such lateralized eye movement should be observed in the mirrored condition. By contrast, if the leftward eye movement is attributed to the facial configuration change caused by facial movement, we should observe similar leftward eye movement regardless of the naturalness of the facial movement. We examined the role of natural facial movement in both younger (3- to 5-months) and older (6- to 9-months) infants, so as to investigate possible developmental changes in the effect of natural facial movement in the LVF attentional bias. We expected that the LVF attentional bias would be stronger in the older group than in the younger group due to development of the face processing network.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Participants

Twenty-five Caucasian infants participated in the experiment. These infants were aged 3–5 months, with a mean age of 128.24 days. An additional 9 infants took part in the experiment, but were excluded from data analyses because of failure to calibrate ($N=2$) or because they did not complete the procedure due to fussiness ($N=7$).

#### 2.1.2. Materials and procedure

Infants were first placed in a car seat. An experimenter helped fasten the seatbelt to make sure that participants would sit still. Participants were then moved underneath a Tobii 2150 eye tracker (50 Hz sample rate) monitor. The monitor was adjusted to face down at the ground and to be parallel to the car seat. This eye tracker and car seat setup ensured that infants could look at the monitor without moving their head and body. The car seat's position was further adjusted to make sure that infants' eyes were aligned with the screen center. The test began immediately after these position adjustments were achieved.

Each test session started with a Tobii default infant calibration procedure, which guaranteed eye tracking precision and accuracy. During the calibration, a cartoon figure was presented on the screen. If infants successfully fixated on the cartoon figure for 1 s, the cartoon figure would move to another position, which was controlled by an experimenter. The calibration procedure ended when participants successfully fixated on the cartoon figure at five positions (4 corners and the center).

After successful calibration, infants watched a series of 30 s face videos presented on the monitor with audio muted. In the natural movement condition, a silent video was presented that depicted the face of a woman counting numbers from one to thirty in English at the speed of one number per second (Fig. 1). In the artificial movement condition, everything was same as that in the natural condition except that the face was horizontally flipped across the vertical midline connecting the center of the nose and mouth, thereby switching the left face side to the right face side, and vice versa for the right face side (Fig. 1). The faces were all shown in frontal view with neutral expression. There were 7 female faces used in the present experiment, all of whom were Caucasian with English as their native language. All videos were presented without audio in order to control for confounds of language processing. The order of the two conditions was counterbalanced across participants.

To ensure the left face half was projected to the left visual field and the right half to the right visual field, several manipulations were performed. First, we rotated the face stimuli to make sure the midline connecting the nose and mouth center points was parallel to the vertical line, and the line connecting both eyes was approximately parallel to the horizontal line. Second, we moved the face stimuli to align the face midline with the screen midline. Third, before the calibration session, each participant's head position was aligned to the screen midline, which would not change throughout the testing session.

### 2.2. Results and discussion

The raw eye tracking data were first filtered to generate the fixation data according to a definition established in previous studies (Liu et al., 2011). A fixation was defined as at least 100 ms continuous gaze with a spatial dispersion of less than 30 pixels. The following results were based on the fixation data analyses.

In order to analyze whether infants showed a looking bias for either side of the face, we created two areas of interest (AOI) covering the left and right face halves. The two face halves were defined according to the middle line connecting the center points of the mouth and nose. From the observer's perspective, the face half to the right of the middle line was named right face half, and vice versa for the left face half. The areas of left and right face side AOIs did not differ from each other, as a one-sample $t$ test indicated that the area of the left face half AOI was not significantly different from 50% of the whole face area ($S_{left}=49.92\%$, $t[6]=.22$, $p=.831$).

As indicated in previous moving face processing studies, facial movement can attract more fixation in the lower face half, which would probably lead to a difference in face processing between the

**Fig. 1.** Snapshots demonstrating the natural (left) and artificial (right) moving face stimuli used in the present study.

upper and lower face halves (Xiao, Liu, Quinn, Ge, Pascalis, & Lee, 2013). In order to highlight the potential differences in face processing between the two face halves, we further analyzed the eye movement patterns in the upper and lower face halves separately. The AOIs for the upper and lower face halves were adjacent to the line that was perpendicular to the middle line and across the center of the nose.

Infants' left visual side preference ratio was derived from the fixation duration on the left half divided by the looking time spent on both left and right halves. A preference ratio of .50 means participants spent an equal amount of time looking at the left and right sides. A ratio greater than .50 indicates that participants looked longer at the left side, while a right side bias would be revealed by a preference ratio of less than .50. We applied this definition for the upper and lower face halves to obtain the preference ratio for both halves separately. It should be noted that there were a few participants who only looked at either the upper ($N=1$ in the artificial condition) or lower face half ($N=1$ in the normal condition; $N=4$ in the artificial condition), which led to no preference scores for the face half they did not look at. We excluded these participants in the statistical analyses. The mismatched *df* values in the following statistical tests reflected this situation.

Preliminary analysis showed that participants looked at the natural and artificial moving faces for the same amount of time ($M_{natural}=12.25$ s, $SD_{natural}=8.38$ s, $M_{artificial}=10.20$ s, $SD_{artificial}=7.39$ s, $t[24]=1.43$, $p=.167$), which indicates there was no significant difference in terms of total looking time for the natural and artificial moving faces. In addition, no age or participant gender effect was observed in the eye movement patterns ($p_s > .050$). The following analyses were therefore conducted with the age and gender variables collapsed.

As shown in Fig. 2, we did not observe the LVF attentional bias either for the naturally (*Ratio* $=.57$, $t[24]=1.58$, $p=.127$) or for the artificially moving faces (*Ratio* $=.50$, $t[24]=.05$, $p=.958$). This finding suggests that, in terms of whole face area, 3- to 5-month-olds spent equal time on the left and right face sides.

For the lower face part, where face movements are salient because of mouth movements, we observed a significant LVF attentional bias in the natural condition (*Ratio* $=.67$). A one-sample *t* test confirmed this bias as being significantly above the chance level ($t[23]=2.42$, $p=.024$). However, no such bias was observed in the artificial condition (*Ratio* $=.57$, $t[20]=.96$, $p=.347$). These results suggest that the natural counting facial movement elicited 3-to 5-month-olds' LVF attentional bias in looking at the lower face half. In contrast, the artificial movement condition failed to stimulate this eye movement pattern, although it had the same image content as the natural condition. The difference suggests that natural facial movements result in more activation in the right hemisphere than artificial facial movements.

For the upper face part, participants' looking time was not significantly different between the left and right face halves (*Ratio* $=.51$, $t[24]=.14$, $p=.887$) when they looked at the naturally presented moving faces. In addition, we did not observe any side bias in the upper face part for the artificially moving faces (*Ratio* $=.43$, $t[23]=-1.03$, $p=.312$). These results indicate that infants did not show a side preference for the upper face part, regardless of whether the faces moved in a natural or artificial way. They further suggest that because of the relative lack of facial movement in the upper face half, infants at 3–5 months were not able to generate the consistent leftward eye movement when looking at the upper face region.

A contributing factor for why the LVF attentional bias was observed for the lower, but not upper face half is that facial movement may have been more salient in the lower left face half. To examine this possible difference in movement saliency, we analyzed facial movement intensity in the moving faces.

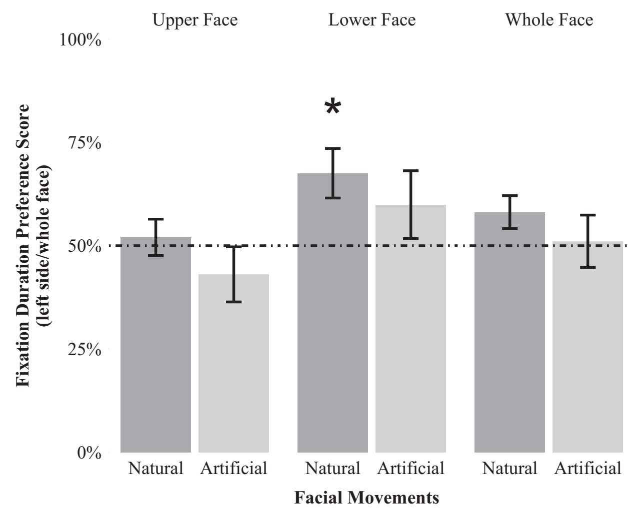


**Fig. 2.** The mean left half preference score for the upper, lower, and whole face areas in 3- to 5-month-olds. A value above 50% indicates that participants looked longer at the left half than at the right half. The error bars represent unit standard errors.

To obtain these measurements, we used the Computer Expression Recognition Toolbox (CERT, Littlewort et al., 2011) to gauge the intensity of facial movement. CERT is a computer program developed to automatize coding of facial movements and expressions from videos in real time. It is based on the principles of the Facial Analysis Coding System (FACS, Ekman & Friesen, 1978), where minute facial movements are coded into action units. Unlike FACS, which is done by trained coders and is laborious and time-consuming, CERT automatically codes facial movements and expressions in real time and produces multi-dimensional frame-by-frame measures of intensities of various facial actions based on the FACS. As part of its functions, the CERT program can automatically detect the positions ($x$ and $y$ coordinates) of each major facial feature (i.e., eyes, nose, and mouth) in each video frame. Based on the coordinates and their changes between frames, CERT estimates an intensity score reflecting the extent to which a particular face feature (e.g., the mouth) has moved from one frame to another. The estimated scores are later normalized by comparing them to a norm based on experts' rating on facial action units (i.e., AUs). The normalized intensity score represents facial movement intensity relative to the norm. A positive intensity value means the facial movement is relatively more intense than normal, while a negative value indicates that the face moves relatively less than the normal. The CERT program provides facial intensity measures on 26 AUs. The intensity scores of these AUs allow us to compare the intensities of movements between the eye and mouth regions.

We averaged the intensities of facial movements across all of the video frames according to their locations (i.e., the eye and mouth regions). As shown in Fig. 3, for the facial movements in the upper face half, intensities were equal to or less than normal. By contrast, for the facial movements in the lower face half, most of the motion intensities were higher than normal. However, in all facial regions, no significant differences in movement intensity between the natural and artificial facial movements were observed ($p_s > .05$). These results suggest that the facial movements in the lower face half were more intense than those in upper face half, which may have contributed to the LVF attentional bias result found here. However, it should be noted that the high saliency of facial movements in the lower face half alone could not account for the present findings because infants failed to show the LVF attentional bias in the lower face half of the artificially moving faces.

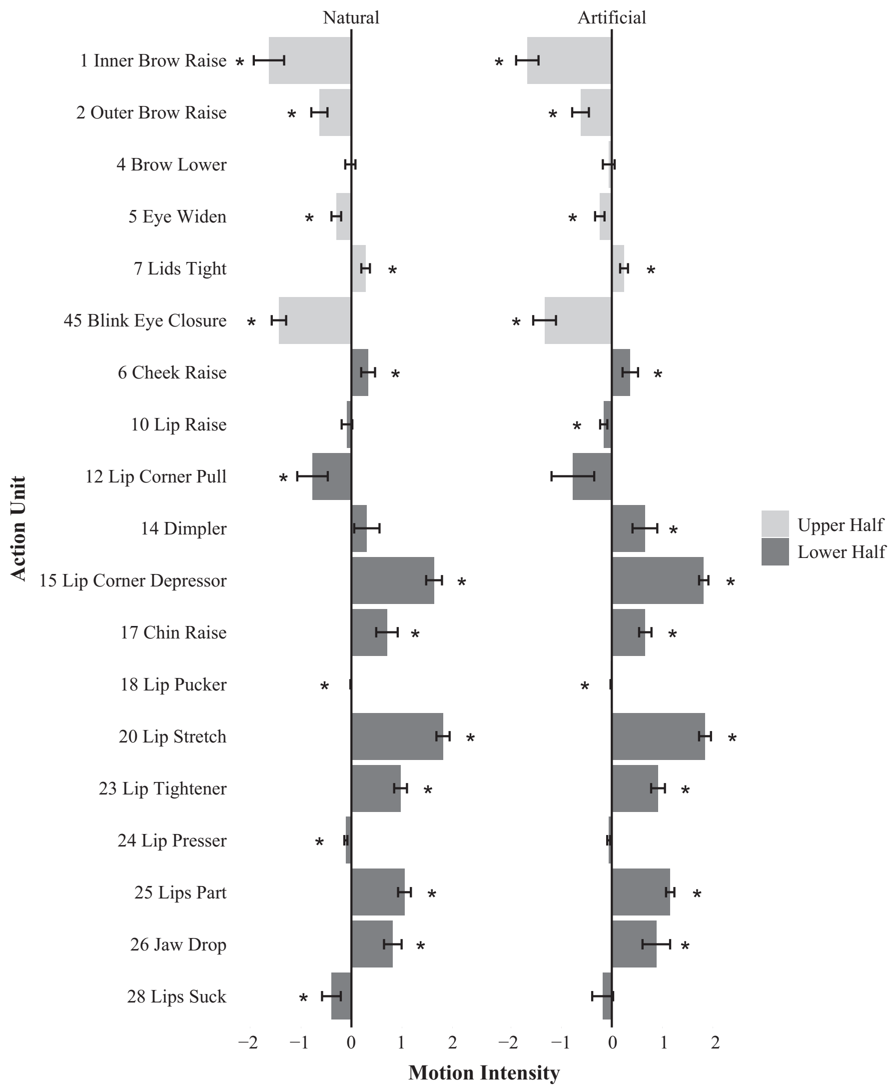


**Fig. 3.** The intensity of facial Action Units (AUs) in the upper and lower halves of naturally and artificially moving faces. The larger numbers represent more intense face movements. Error bars represent unit standard errors of the mean intensity scores. Asteroid markers indicate that the motion intensities are significantly higher or lower than that of normal movement at the significance level of .050. The results show that facial movements in the upper face half (light gray bars) were less intense than those in the lower face half (dark gray bars). No significant differences in movement intensity between the natural and artificial facial movements were observed.

The specificity of the LVF attentional bias for the naturally moving faces points toward an underlying role for face experience in driving the leftward eye movements. Faces that moved in a way that infants normally experience appeared to be able to stimulate the LVF bias. Following this argument, we might expect the LVF attentional bias to increase with age for naturally, but not artificially moving faces, as older infants would have more experiences with moving faces than younger infants. To investigate this prediction, we conducted Experiment 2 with older infants at 6–9 months of age.

## 3. Experiment 2

In Experiment 2, we further examined the role of natural facial movement in the LVF attentional bias in infants around 6–9 months of age. Older infants, as compared to younger infants, have more face experience. Thus, we expected to observe a more significant LVF attentional bias specific to the naturally moving faces in older infants. We used the same experimental procedure as in Experiment 1 except that the natural and artificial face movement conditions were between-subject.

### 3.1. Method

#### 3.1.1. Participants

Thirty-one infants 6–9 months of age participated in the current experiment ($M_{age}$=221.42 days). An additional 3 infants participated in the present study, but were excluded from data analyses because of program error ($N$=1) or because they did not complete the procedure due to fussiness ($N$=2).

#### 3.1.2. Materials and procedure

The materials for the current experiment were identical to those used in Experiment 1. The only difference in the procedure was that we used a between-subject design in Experiment 2. Each infant was randomly assigned to the naturally or artificially moving face condition. The between-subject design was implemented because pilot work showed that eye tracking data quality decreased dramatically during the second block (i.e., condition) due to infants' fussiness or reluctance to look. For the following data analyses, there were 17 infants in the natural condition ($M_{age}$=219.53 days), and another 14 infants in the artificial condition ($M_{age}$=223.71 days).

### 3.2. Results and discussion

We applied the same fixation filter to generate fixation statistics from the raw gaze data. As in Experiment 1, the left visual field preference analyses were conducted on the whole face area as well as on the upper and lower face halves, respectively.

Preliminary analysis showed that participants looked at the natural and artificial moving faces for the same amount of time ($M_{natural}$=9.65 s, $SD_{natural}$=8.51 s, $M_{artificial}$=11.07 s, $SD_{artificial}$=4.61 s, $t$[29]=.56, $p$ =.581). No age or gender effects were observed in eye movement patterns ($p_s$ > .050). The following analyses were thus conducted with the age and gender variables collapsed.

In terms of the whole face area, we observed a significant LVF attentional bias specific to the naturally moving faces (*Ratio* =.73, $t$[16]=3.22, $p$ =.005). By contrast, infants spent equal amounts of time looking at the left and right sides of the artificially moving faces (*Ratio* =.52, $t$[13]=.22, $p$ =.832). These results further support the argument that natural facial movement facilitates a LVF attentional bias in the whole face area in older infants.

For the lower face half, we observed a LVF attentional bias for the naturally moving faces (*Ratio* =.78, Fig. 4), which was confirmed by a one-sample $t$ test against chance level ($t$[16]= 3.77, $p$ =.002). However, we failed to observe a significant LVF attentional bias in the artificial movement condition (*Ratio* =.58, $t$ [13]=.88, $p$ =.393). These results are consistent with the finding in Experiment 1 that only the natural, but not the artificial, facial movement elicited the LVF bias.

For the upper face half, we observed a similar LVF attentional bias. Only the naturally moving faces led to a significant LVF attentional bias (*Ratio* =.71, $t$[15]=2.57, $p$ =.021). By contrast, those infants who watched the artificially moving face did not show the LVF attentional bias in the upper face half (*Ratio* =.54, $t$ [13]=.45, $p$=.653). It is interesting that the LVF attentional bias was only observed in the upper half of the naturally but not artificially moving face, given that eye blinking depicts vertical movement which should be perceived similarly in naturally and artificially moving faces. It could be that LVF attentional bias in the upper half of naturally moving faces is facilitated by the natural facial movement in the lower half. That is, the natural facial movement in the lower face half might scaffold the LVF in the upper face half, whereas artificial facial movement in the lower half resulted in equal looking time for each side of the face.

Taking the LVF attentional bias scores from Experiments 1 and 2 together, we further examined whether the LVF attentional bias increased with age. For looking at the naturally moving faces, independent sample $t$ tests were conducted for the whole face area, upper face half, and lower face half, respectively. Consistent with our hypothesis, the older group showed a larger LVF attentional bias within the whole face area than the younger group in watching naturally moving faces ($t$[40]=2.11, $p$ =.041). This bias was also significant in the upper face half ($t$[39]=2.38, $p$ =.022), but not in the lower half ($t$[39]=1.29, $p$=.206).

In addition to the age related LVF bias increase, we observed an interesting age related eye movement pattern in terms of a lower face half biased fixation shift. The proportional lower face looking time was derived from the fixation duration on the lower face half divided by the looking time spent on both upper and lower halves. We ran an ANOVA to examine the effect of age (old and young) and facial movement type (natural and artificial) on infant's proportional lower face looking time. The results showed that the older group spent significantly longer time looking at the lower face part ($M$=55.33%) than the younger group ($M$=36.88%, $F$ [1, 75]=7.53, $p$ =.008). It suggests that, with the increased age, infants were increasingly sensitive to the facial movement in the lower face part. This result is consistent with several previous findings that, in the first year of life, infants gradually shift their gaze from the eye region to the mouth region when looking at moving faces (e.g., Hunnius & Geuze, 2004; Lewkowicz, & Hansen-Tift, 2012). However, it should be noted that this mouth oriented fixation shift pattern for moving faces might not be universal. As

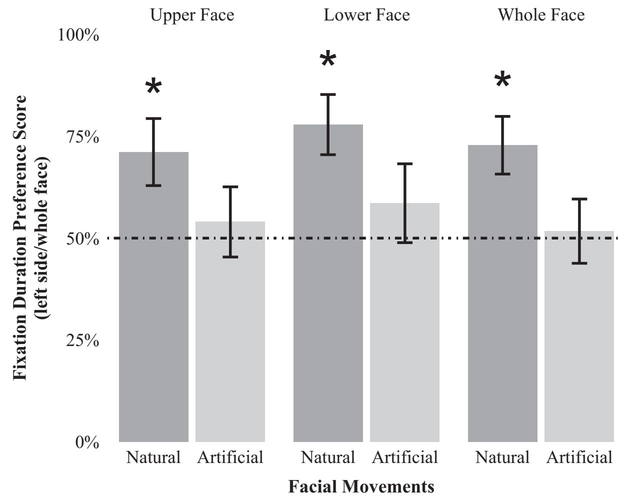


**Fig. 4.** The mean left half preference score for the upper, lower, and whole face areas in 6- to 9-month-olds. A value above 50% indicates that participants looked longer at the left half than at the right half. The error bars represent unit standard errors.

shown in one recent study, infants at 9 months of age exhibited an increasing eye fixation pattern when they watched a dynamic face video that included socially engaging motion signals, such as smiling and hand waving (Wilcox, Stubbs, Wheeler, & Alexander, 2013). In addition, we did not find any effect of natural versus artificial facial movements in terms of the main effect ($F$[1, 75]= 1.50, $p$ =.224) or the interaction ($F$[1, 75]=.29, $p$ =.592). The non-significant results between natural and artificial facial movements indicate that the lower face biased fixation shift is not related to the naturalness of facial movements, but perhaps to the motion itself. They are in accord with one of the recent findings that language irrelevant facial movements (i.e., chewing) also led to an increasing lower face biased fixation shift with age (Xiao, et al., 2013). They further suggest that the facial motion signal itself could play a role in infants' moving face scanning pattern.

## 4. General discussion

The present study investigated the emergence and development of the LVF attentional bias in infants' face processing. Specifically, we examined the LVF attentional bias when infants watched naturally and artificially moving faces. The results demonstrated a significant LVF attentional bias emerging in 3- to 5-month-olds specifically when they looked at the lower half of the naturally moving faces. In addition, we observed a developmental change in the LVF attentional bias in infancy. With increased age, the LVF attentional bias spread from the lower face half to the whole area. We interpret these results as evidence demonstrating the importance of exposure to naturally moving faces in the development of face processing in the early months of life.

The observation of the LVF attentional bias is in accord with previous findings on specific eye movement patterns during face processing. Studies have consistently shown that observers bias their eye movements to the face half in their left relative to right visual field by showing either proportional or initial looking time differences (Butler et al. 2005; Butler & Harvey, 2006; Dundas & Best et al. 2012; Dundas & Gestgeb et al. 2012; Guo et al., 2012; Hsiao & Cottrell, 2008, 2009; Mertens et al., 1993; Schyns et al., 2002). These prior studies also indicated that the leftward biased eye movement pattern in face processing is robust and not restricted by task requirements. For infants, using a passive looking task, previous studies observed that the LVF attentional bias existed as early as 6 months of life (Guo et al., 2009). The present study further showed that the LVF attentional bias emerges even earlier in infancy, around 3–5 months after birth.

We found that the LVF attentional bias in early infancy was elicited only by naturally moving faces. By contrast, when looking at artificially moving faces, the infants who exhibited the significant LVF attentional bias for naturally moving faces failed to show this looking pattern. Note that the face movements in the two conditions were identical in intensity and other physical characteristics. The only difference was that in the natural condition the faces moved in a way that infants would have typically seen in their environment, whereas in the artificial condition the same faces moved in the opposite manner to what infants had experienced. The contrast between the two conditions suggests that experience plays an important role in the emergence of the LVF attentional bias in infant face scanning, and implies that infants have already developed sensitivity to genuine facial movements around 3–5 months of age. Only facial movements presented in the way in which infants normally experience can stimulate the LVF bias. This argument is consistent with previous findings that infants show spontaneous preference to biologically possible facial movements but not to biologically impossible ones (Ichikawa, Kanazawa, & Yamaguchi, 2011), and that infants pay attention to individual facial movement patterns as early as 4 months of age (Spencer, O'Brien, Johnston, & Hill, 2006). The finding of a specific LVF bias in response to natural facial movement reflects either the role of familiarity of natural facial movement or the biological significance specifically embedded in naturally moving faces. The development of the LVF bias for natural facial movements might be due to the increasing familiarity of facial movements. However, it should be noted that the present findings cannot completely rule out the effect of biological significance in the LVF bias, as such a bias might drive the LVF bias at a stage earlier than the present study has examined. Future investigations might consider using facial movement training procedure to specifically examine the roles of familiarity and biological significance in the development of the LVF bias. Taken together, these studies suggest that natural facial movement is important to infant face processing, and can activate the LVF attentional bias in early infancy.

Our findings support the suggestion that the right hemisphere specialization for face processing may emerge early in infancy. This hemispheric lateralization has been reported as early as 4–6 months of age in prior behavioral and neuroimaging studies. For example, de Schonen and Mathivet (1990) reported that infants from 4 to 6 months learned a face presented in the left visual field better than a face presented in the right visual field, suggesting the right hemisphere is more sophisticated in processing face stimuli. In several recent studies using advanced neuroimaging techniques, researchers also observed a right hemisphere specific response to face stimuli before 6 months of age. Otsuka et al. (2007), for example, reported that infants at 5–8 months showed differentiated neural activities in response to upright and inverted faces only in the right superior temporal sulcus region. Consistent with this finding, Nakato et al. (2009) further demonstrated the development of right hemispheric lateralization for face processing. They observed that 5-month-olds showed right hemisphere lateralization only for frontal-view faces, while 8-month-olds exhibited right lateralization for both frontal- and profile-view faces. Moreover, the present findings suggest that this early right hemisphere lateralization can be revealed by infants' eye movement patterns when viewing naturally moving faces as early as 3 months of age. Thus, the findings from the existing and present studies taken together suggest that right lateralized processing of faces develops within a very short period of time, which might likely follow the commencement of using cortical structure to process visual stimuli in general and faces in particular (de Haan & Groen, 2006; Johnson, 2005).

The present findings revealed a developmental change in the LVF attentional bias in processing naturally moving faces in the first year of life. The counting movements around the mouth may have stimulated the emergence of a LVF attentional bias around 3–5 months of age specifically in the lower face half. However, as was mentioned earlier, salience in the mouth region cannot be the sole basis for the earlier emergence of the LVF attentional bias in the lower face half because the bias was not observed in the artificial movement condition. Moreover, with increased age, the natural facial movement's facilitation effect on the LVF attentional bias spreads out to the whole of the face. This developmental change implies that increased moving face experience obtained within the first year of life may drive the specific LVF attention bias in processing naturally moving faces. With increased age, infants become increasingly familiar with naturally moving faces, thereby leading to an age related LVF attentional bias increase activated only by naturally moving faces.

The difference in the LVF attentional bias pattern between two age groups might further reflect the development of face processing between 4 to 10 months of age (Cashon & Cohen, 2004; Cohen & Cashon, 2001; Schwarzer, Zauner, & Jovanovic, 2007). As indicated by Schwarzer et al. (2007), infants' ability to integrate facial information from face parts develops rapidly within the first year of life. Four-month-olds processed faces mainly in a part-based way, whereas 10-month-olds tended to use an integrative way to process face stimuli. This switch in face processing could explain why we only observed the LVF attentional bias in the lower face half in 3- to 5-month-olds. Because of part-based face processing, these infants only exhibited a LVF attentional bias in the region where salient natural facial movement was located, and were unable to use local facial movement to generate a LVF attentional bias for the upper face half. By contrast, older infants may process faces in a more integrative way. They could join the facial movement information from the lower face half into a representation of the whole face, thereby leading to a LVF attentional bias for the whole face area.

As shown in one adult study, the LVF attentional bias was observed only in watching pictures of upright human faces, but not those of inverted faces, objects, or landscapes (Leonards & Scott-Samuel, 2005). This observation was supported by a finding that the LVF perceptual bias in children was only observed in human face processing, but not in monkey face processing (Balas & Moulson, 2011). By contrast, adults seem less sensitive to facial movement by showing a similar LVF attentional bias for natural and artificial facial movements (Everdell, Marsh, Yurick, Munhall, & Pare, 2007). This suggests that adults develop a specific LVF attentional bias to upright human faces. Moreover the specificity of this bias appears to mostly rely on static facial information, rather than on the dynamic aspect of facial information.

However, infants seem to not have developed such specificity in their eye movement patterns, as 6-month-olds exhibit the LVF attentional bias not only for upright static face pictures, but also for pictures of monkey faces and objects (Guo et al., 2009). Yet, the present study showed that young infants' LVF attentional bias in face processing depends on the naturalness of facial movements. Taking these findings together, infants have been shown to be sensitive to facial movements but not to face versus non-face static pictures, whereas adults were shown to be sensitive to the face versus non-face static pictures, but not to the facial movements. This pattern suggests a developmental change in the relative importance of dynamic and static facial information in face representation in infants and adults. For infants, moving facial information might be more important than static facial information, probably because dynamic information is more salient than static information. Adults may rely more on static facial information for face processing, while facial movement information becomes secondary (the supplemental hypothesis, O'Toole, Roark,

& Abdi, 2002). Although the current findings do not provide direction evidence for this face representation shift, future studies might continue examining the proposal with more specific paradigms.

To conclude, the present study observed the LVF attentional bias in infants when they watched naturally moving faces but not when they watched unnaturally moving faces, which suggests hemispheric specialization for face processing. More importantly, by introducing natural facial movement, we observed the LVF attentional bias earlier than what was reported in previous studies, most of which used static face images as stimuli. The findings specifically indicate an important role for visual experience of natural facial movements in infant face processing.

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