Children's facial emotion recognition skills: Longitudinal associations with lateralization for emotion processing

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Abstract

This is the first longitudinal study to evaluate the relations between hemispheric laterality for emotion processing and the development of facial emotion recognition skills, both of which show similar developmental trajectories. Five to 12-year-old children (N = 160) completed an emotion discrimination task, emotion matching task, identity matching task, and behavioral lateralization for emotion processing task at baseline and one year later. Lateralization at baseline predicted later emotion discrimination, while change in strength of lateralization across the year predicted emotion matching ability. Lateralization was not a significant predictor of identity matching. These findings provide evidence that it is changes in laterality for emotion processing that contribute to improvements in facial emotion recognition skills between 5 and 12 years of age.

Key words: emotion recognition, hemispheric lateralization, emotion processing

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The ability to quickly process and accurately recognize emotions in others is a key social skill that aids successful social interactions. However, beyond some of the developmental milestones in emotion recognition, little is known about how the processing of emotions in the brain is linked to performance on emotion recognition tasks. This study is the first longitudinal study to explore the role of lateralization for facial emotion processing in the brain in children's developing facial emotion recognition (FER) ability.

Developmental changes in FER have been widely investigated. It is known that children are able to recognise the six basic emotions (happy, sad, angry, fear, surprise, and disgust; Ekman, Sorenson, & Friesen, 1969) between the ages of 4 and 11 years (e.g., Chronaki, Hadwin, Garner, Maurage, & Sonuga-Barke, 2015; Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007; Herba & Phillips, 2004; Reinchenbach & Masters, 1983). Taken together, research typically finds that happiness is recognized earliest, followed by anger or sadness and then surprise or fear and finally disgust. Despite these trends being identified, it is still not fully understood how children develop their FER skills.

Interestingly, developmental trends in early to middle childhood of children's strength of hemispheric laterality for facial emotion processing emerge in a similar timeframe as those found for FER. Patterns of lateralization for facial expressions of emotion have been shown to emerge between 5 and 11 years of age, with happy emotions showing right hemisphere (RH) lateralization at 5 years (Levine & Levy, 1986; Workman, Chilvers, Yeomans, & Taylor, 2006). Workman et al. (2006) have shown that sad, anger, surprise, and disgust facial emotions become RH lateralized by 7-8 years, and fear by 10-11 years (see Watling, Workman, & Bourne, 2012, for a detailed review of the literature).

To reconcile the understanding of developmental changes in FER, it is important to explore the links between FER skills and brain development (including hemispheric laterality for emotion processing and maturation of neural processes). This work explores these links longitudinally, using behavioral measures to assess patterns of lateralization, enhancing the understanding of if maturation of the brain may support the development of children's FER, or if it is vice versa.

Whilst there are three main theories for the pattern of lateralized recognition of emotional expressions — the valence hypothesis, the approach-withdrawal model, and the right hemisphere hypothesis — much research supports that facial emotion is primarily lateralized for emotion processing in the RH (e.g., Aljuhanay, Milne, Burt, & Pascalis, 2010; Ashwin, Wheelwright, & Baron-Cohen, 2005; Borod et al., 1998). Research with adults has found that RH brain-damaged patients were markedly impaired relative to left hemisphere (LH) brain-damaged patients in the recognition of emotions in facial expressions (Bowers, Bauer, Coslett, & Heilman, 1985; DeKosky, Heilman, Bowers, & Valenstein, 1980; Kucharska-Pietura & David, 2003).

A common method that is used to assess lateralization patterns of FER in the brain is the chimeric faces task (CFT), a behavioral, free-viewing measure of laterality. In the CFT two chimeric faces are presented to participants, one above the other (see Figure 1). The two chimeras are mirror images of each other. Each chimeric image displays a face which has one side neutral and the other side emotional. Participants are asked which of the two faces is more emotional. The more often participants choose the face that has the emotion on the left side of the image (left visual field, LVF), the more RH dominant for facial emotion processing the participant is; whereas, the more often participants choose the face that has the emotion on the right side of the image (right visual field, RVF), the more LH dominant for facial emotion processing the participant is.

The CFT has been validated as a test of laterality. Evidence from unilateral brain damaged adults (Kucharska-Pietura & David, 2003) and children (Bava, Ballantyne, May, & Trauner, 2005) has shown that those with RH brain damage showed no clear side bias on the CFT, whilst those with LH brain damage were more likely to choose images with the emotion presented in the LVF, indicating RH processing. Coronel and Federmeier (2014), using eye-tracking techniques, demonstrated that participants who choose the chimeric image with the emotion presented in the LVF did not do so because of default scanning biases (or attentional predispositions), but did so due to RH processing mechanisms. Recent EEG evidence from Damaskinou and Watling (2017) found that when viewing chimeric images that have the emotion presented in the LVF, there is greater RH activation than when the emotion is presented in the RVF. Further, when comparing the CFT to other classic behavioral measures of laterality (i.e., divided visual field), Bourne (2010) has demonstrated that participants' laterality scores on the two tasks are strongly correlated providing evidence that it is sensitive to the detection of patterns of laterality. A recent meta-analysis (Voyer, Voyer, & Tramonte, 2012) has demonstrated that there is a large and significant LVF effect (participants are more likely to judge that the chimeric image is more emotive when the emotion is presented in the LVF than the RVF) across studies that have used the free-viewing CFT. Importantly, the CFT has been successfully used with children from 5 years of age (e.g., Aljuhanay et al., 2010; Chiang, Ballantyne, & Trauner, 2000; Levine & Levy, 1986; Workman et al., 2006). Given that the CFT employs a simple methodology that has successfully been used with young children in the past (from 5 years) we have chosen to use this task to assess the strength of lateralization for facial emotion processing.

Whilst there is converging evidence across methodological approaches showing a RH advantage in the processing of emotions, only a few studies have explored the connection of hemispheric lateralization for the processing of emotions with the ability to recognize emotions. Boles, Barth, and Merrill (2008) presented a model to explain the link between hemispheric laterality for emotion processing and skills development (e.g., language, emotion recognition skills). Their model would expect that as emotion recognition becomes lateralized for emotion processing later in childhood (by 10 years), at a point when brain maturation is slowing, that being more strongly lateralized for emotion processing would aid task performance (i.e., expect a positive relation). Very few studies have investigated this link directly, but those that have done so support this model, in that there is a positive relation between strength of lateralization and emotion recognition ability (e.g., Barth, Boles, Giattina, & Penn, 2012; Watling & Bourne, 2007; Workman et al., 2006). For instance, Workman et al. (2006) showed that there was a significant positive correlation of 5- to 11-year-old strength of RH lateralization for emotion processing and their ability to recognize emotions expressed in a set of eyes. Moreover, Watling and Bourne (2007) found a positive relation for 10-year-olds between strength of lateralization for processing emotions and their ability to judge what emotion a protagonist would display when hiding their true feelings for self-representation motivations. Both of these studies explored emotion recognition in complex situations (i.e., required a theory of mind to infer what another is feeling from the eyes, and what someone might be feeling on the inside versus displaying on the outside). Whilst we often interpret emotions in complex situations, we also need to discriminate one facial expression from another. Watling and Bourne (2013) found that 6-year-olds, but not 8- and 10-year-olds, who were more strongly lateralized to the RH for emotion processing, were more accurate on an emotion recognition task.

To understand the role of lateralization for emotion processing in the development of FER skills, we have included two FER tasks that vary in difficulty and we have included a facial control task; all tasks were adapted from Bruce et al.'s (2000) battery of FER tasks for children. Each task includes images of facial expressions of emotion but require different decision-making processes. The emotion discrimination task, which asks children to decide which of two presented facial images expressed a particular emotion, examines conceptual knowledge of emotion (i.e., ability to recognize an expression as belonging to the category of a specific emotion, such as happy, sad, etc.). The emotion matching task, which asks children to look at an image of a target face and then decide which of the two facial images presented below the target image expresses the same emotion as the individual in the target image, investigates categorical knowledge of emotion (i.e., ability to visually distinguish basic emotions from one another). The identity matching task, which asks children to look at an image of a target face and then decide which of the two facial images presented below the target image is the same person as the individual in the target image, requires children to ignore the emotion and match the target face to who was the same individual below.

In the emotion tasks, we included five of the six basic facial expressions of emotion (happy, sad, anger, fear, surprise) and neutral facial expressions. The facial expression of disgust was not used because it has been found to only develop around 11 years of age (e.g., Durand et al., 2007). This study included emotions that are recognized by middle childhood. Further, whilst much of the research to date focuses solely on assessing laterality for happy faces, in the CFT we have included happy, sad, and angry chimeras; happy and sad emotion processing appears to be lateralized to the RH from 5-6 years, and angry emotion processing from 7-8 years (Workman et al., 2006).

As both FER and laterality for emotion processing develop over time for differing emotions (e.g., Bruce et al., 2000; Herba & Phillips, 2004; Workman et al., 2006), we had 5 to 6 year olds, 7 to 8 year olds, and 9 to 10 year olds participate in this longitudinal study. It was expected that older children's performance would be more accurate than younger children's and that children's FER and identity matching scores would improve over the one year period. Further, we assess if changes in laterality for emotion processing occur over a one year period and if lateralization is stronger in older children than the younger children, as pervious research has found: Chiang et al. (2000) found RH lateralization for the processing of happy emotions was stronger in 10-year-olds than 6-year-olds, while Workman et al. (2006) found no such change for happy emotion processing but did for angry emotion processing.

Crucially, we explore how laterality for facial emotion processing is related to FER. It is expected that children's strength of lateralization to the RH for emotion processing at baseline will positively predict FER accuracy one year later, as will changes in the strength of lateralization. Given that the CFT used is designed to be a test of lateralization for emotion processing and not identity, it is expected that lateralization for emotion processing should not predict performance on identity matching. Further, to gain insight into if children's FER ability influences their strength of lateralization for emotion processing, we will assess if we can predict strength of lateralization for emotion processing from FER accuracy; we have no clear hypothesis about this. Whilst we expect that changes in hemispheric specialization for processing of emotions in the brain across the one year time span will influence FER accuracy, it is less clear if improvements in FER accuracy will support increasing hemispheric specialization for processing of emotions in the brain.

In addition to the key predictors, we assessed if age and sex moderate the relation between laterality for emotion processing and task performance. It is expected that as the emotion discrimination task is easier than the emotion matching task (see Bruce et al., 2000) that we may see a relation in the two younger groups that do not exist in the oldest group of children. Furthermore, given that females tend to be better at emotion recognition tasks (McClure, 2000) and males tend to be more strongly lateralized for emotion processing than females (e.g., Bourne, 2005) we may see differing patterns for the two sexes.

Methods

Participants

Two hundred and eleven children (63 six-year-olds, 68 eight-year-olds, and 80 ten-year-olds) from two British Schools, one in a working-class neighborhood and of mixed ethnic background and one in a middle-class neighborhood and primarily White British participated in the first time point of this study. Of these, 173 children participated at time 1 and on average 359.91 days (SD = 7.47 days, range 328 to 372 days) later participated at time 2, resulting in an attrition rate of 21.97% (primarily due to child being absent on the second day of testing). The children who participated at both time points included 51 six-year-olds (M = 6.38 years, SD = 0.29, range 5.92-6.86 years, 27 girls), 53 eight-year-olds (M=8.32 years, SD = 0.30, range 7.85-8.83 years, 27 girls) and 69 ten-year-olds (M= 10.34, SD = 0.30, range 9.87-11.01, 39 girls). Analyses showed that those who were present and participated at both time points did not differ significantly on any of the time 1 measures from the children who participated only at time 1 (all *p*s > .60). The Heads in both schools preferred to use an opt-out form for consent; parents were sent information regarding the study and asked to return the form to the class teacher if they wished for their child not to participate. Verbal assent was also obtained from all the children. This study was approved by the Department Ethics Committee.

Participants signed their name on the top half of a piece of paper and then picked up the child scissors and cut the paper in half. The researcher recorded which hand they used for these two activities and when using the computer mouse to assess handedness. Children who used their left hand for any of the three activities were excluded from additional analyses. In total 13 children were excluded because of their handedness (final N = 160), resulting in the final sample being 48 six-year-olds (M = 6.37 years, 26 girls), 49 eight-year-olds (M = 8.32 years, 26 girls) and 63 ten-year-olds (M = 10.34, 35 girls).

Materials

Four tasks were used in this study: the chimeric faces test (CFT), an emotion discrimination task, an emotion-matching task and an identity matching task. Stimuli were black and white NIMH (National Institute of Mental Health; Tottenham et al., 2009) images, displaying no emotion (neutral) and five emotional facial expressions (happy, sad, fearful, angry, and surprised). All faces, posed in full frontal orientation, expressed the emotion at 100% of intensity and had a black oval mask framing the face to remove additional features (e.g., hair, ears). The NIMH faces were used to create happy, sad, and angry chimeras.

The tasks were randomly presented to participants on a Dell Inspiron 15-inch laptop computer or a 15-inch desktop in the ICT suite of the school. Runtime Revolution (2007, Version 3.0) software allowed for simultaneous presentation of stimuli with all verbal components (e.g., instructions, target emotion if task-appropriate) for each task presented both visually on the screen and auditorily via a set of headphones. Children responded by clicking the mouse and responses were recorded by the software. For the emotion discrimination, emotion matching, and identity matching tasks children were provided with a mouse that had a green piece of paper on the left mouse button and a yellow piece of paper on the right mouse button; clicks on each mouse button were recorded as separate responses corresponding to the image choice – children clicked the right hand button if they believed the target image was on the right, and the left hand mouse button if they believed the target image was on the left.

Chimeric Faces Test (CFT): Six happy, sad, and angry chimeras were created from grayscale NIMH images. To create each chimeric face an emotive half face image (at 100% intensity) was merged with neutral half face image of the same model to create a whole face, using the nose as a joining point; a mirror image was then created. This resulted in one face that had the emotive half face in the RVF and the neutral half face in the LVF, and a second image that had the emotive half face in the LVF and the neutral half face in the RVF. The two chimeric faces (mirror images of one another) were presented simultaneously, one on the top and one on the bottom (see Figure 1). Each face subtended approximately 6.5° horizontally and 9° vertically. The distance between the two faces was 0.001°. Each pair is presented twice, once with the chimeric face with the emotion in the LVF at the top and a mirror image with the emotion in the RVF at the bottom and a second time with the faces presented in the reversed position (emotion in the RVF at the top and a mirror image with the emotion in the LVF at the bottom). Presentation of the stimuli was blocked by emotion (happy, sad, and angry) with instructions presented prior to each block to keep children focused on the task. Within each block there were 12 trials. In each trial, children were asked to concentrate on the faces and decide which they thought looked happier, sadder, or angrier (depending on the block) and to click on their choice. The images were presented centrally with the cursor positioned in the middle between the two faces so that any upward movement would enable children to click on the top face and any downward movement would enable them to click on the bottom face. The pictures stayed on the screen until the children responded. From the responses a laterality quotient (CFT-LQ) for emotion processing was calculated in the same way as in Bourne (2005) with the total number of times the image with the face in the LVF was chosen minus the total number of times the image with the face in the RVF was chosen; this score was then divided by the total number of trials, resulting in scores ranging from -1 to +1 (-1: always choose the emotion in the RVF indicating left hemisphere advantage, +1: always choose the emotion in the LVF, indication of right hemisphere dominance). Due to the CFT being divided into blocks by emotion, we computed individual scores for each of the three emotions (happy, sad, and angry).

Emotion discrimination task: As in Bruce et al. (2000), children in this task were presented with a pair of full faces which were of the same sex, but displayed different facial expressions (happy, sad, angry, fear, surprise, and neutral; see example in Figure 2a). One face was the target image and the second was a distracter non-target image. Importantly, before the images were presented, children were asked to choose the face expressing the target emotion (e.g., “Which face of the two faces do you think looks happy?”). Following this instruction, children were presented with the two faces simultaneously. In total there were 36 trials, 6 trials for each facial expression. In half of the trials a male identity was used and in half a female identity. Two versions of the task were created: version 1 had 17 pairs of two faces that were the same identity and 19 pairs with different identities, version 2 had 19 pairs of two faces that were the same identity and 17 pairs with different identities. In line with Bruce et al., varying the identity of the pairs allowed us to embed task difficulty, where when the individual in the pair was the same it would make the trial more difficult (configural information of the face will interfere), while when it was different individuals in the pair it would be a simpler trial (focus would be on the emotion only). In half of the trials the correct response was on the left, and in half of the trials the correct response was on the right. Children received a 1 if they clicked the correct response or 0 if they clicked the incorrect response. In line with Bruce et al., scores were totaled for an emotion discrimination score ranging from 0 to 36, and the percentage correct was calculated.

Emotion-matching task: As in Bruce et al. (2000), children were presented with three faces on the screen, all of the same sex. One face was at the top centre, the target stimulus, and two faces were at the bottom, side by side, on the left and right of the screen, the choice stimuli. The target and one of the choice stimuli were expressing the same emotion at 100% of intensity. The other choice stimulus had a different expression expressed at 100% intensity (one of the other five; see example in Figure 2b). Participants were asked to match the emotion displayed on the face of a target stimulus with one of two choice stimuli below it that displayed the same emotion. In half of the trials one of the choice stimuli was of the same identity as the target stimulus but displayed a different emotion (identity as a distractor), and in half of the trials the three stimuli had different identities. In total there were

36 trials, 6 for each facial expression as target. In half of the trials a male identity was used and in half a female identity. To control for side of presentation, and mouse button pressed (left or right), as well as location of target image, two versions of the task were created: version 1 had half of the correct trials with the choice stimuli on the bottom left and half were the correct choice on the bottom right, version 2 had the two images swapped locations (so reversed from version 1). Children received a 1 if they clicked the correct response or 0 if they clicked the incorrect response. In line with Bruce et al. scores were totaled for an emotion discrimination score ranging from 0 to 36, and the percentage correct was calculated.

Identity matching task: As in Bruce et al. (2000), children were presented with three faces on the screen, all of the same sex. One facial image was at the top centre, the target stimulus, and two faces were below, side by side, on the left and right of the screen, the choice stimuli. One of the choice stimuli was the same identity as the target stimulus. In half of the trials the target facial image was neutral and the correct choice facial image was showing an emotion and in the other half of the trials the target facial image was showing an emotion and the correct choice stimulus facial image was neutral. In all trials, the second choice stimuli had a different identity to the target stimulus and had a neutral facial expression (see example in Figure 2c). Children were required to ignore the emotion, and to decide which of the two images on the bottom were of the same person as the one on the top. The target stimulus was of the same sex as the two choice stimuli. There were a total of 22 trials, half with images of male faces and half with images of female faces. As with the emotion matching task, to control for side of presentation, and mouse button pressed (left or right), as well as location of target image, two versions of the task were created: version 1 had half of the correct trials with the choice stimuli on the bottom left and half were the correct choice on the bottom right, version 2 had the two images swapped locations (so reversed from version 1). Children received a 1 if they clicked the correct response or 0 if they clicked the incorrect response. Scores were totaled for an identity matching score ranging from 0 to 22, and the percentage correct was calculated.

Procedure

Participants were seen either in small groups of four in a quiet area of the school or as a whole class in their school ICT suite. Children's handedness was assessed, as outlined in the participants' information. Once seated individually in front of the computer or laptop, children were asked to put on the headphones, enabling them to hear a recording of all verbal components of the tasks at the appropriate points in the program. The order of the tasks for each child and of the trials within each task was randomly assigned through the Revolution Studio program. For the CFT, the order of presentation for the blocks was also randomized. For the emotion discrimination, emotion matching, and identity matching tasks, children had five practice trials, so that they could get used to the task. For the practice trials children were shown an image for where to place their fingers on the mouse (right and left side) followed by instructions that to respond they should click the button that was on the same side as they face that they wished to choose; if children chose the incorrect face they were told "Oops, this face looks very similar. Did you mean to press that button? Try again." Following the five practice trials all children progressed to a secondary instruction screen that reminded participants what they were required to do before starting the trials. When children were ready they would press the 'Begin' button. Once the child responded the program went automatically to the next trial and when the set of trials were completed, the program automatically progressed to the next block or task until the children completed all tasks. Upon completion of the tasks a thank you screen appeared and children were given the opportunity to ask any questions. The same set of tasks and procedure was used at both time points.

Design and analyses

There are four key measures within this study: laterality for emotion processing, emotion discrimination performance, emotion matching performance, and identity matching performance. To assess if facial emotion recognition performance changed over time, and if the tasks differed in difficulty, we first conducted a mixed design ANOVA with age group (6-7, 8-9, 10-11 years) and sex (male, female) as between subjects factors and task performance (emotion discrimination, emotion matching) and time-point (time 1, time 2) as the repeated measures. Similarly, we conducted a mixed ANOVA to assess changes in identity recognition performance. Further, we conducted a mixed ANOVA to assess changes in laterality for emotion processing, replacing task performance with emotion laterality quotient (happy, sad, angry) as a repeated measure. Importantly, to address our main research questions we use multiple regression analyses to assess how laterality for emotion processing may be predictive of performance at time 2 (emotion discrimination, emotion matching, identify matching), as well as how task performance may be predictive of laterality for emotion processing at time 2.

Results

Assessing changes over time

Facial emotion recognition. See Figure 3 for mean percent correct by age and time point. There was a main effect of time, $F(1, 154) = 10.15$, $p = .002$, $\eta^2 = .06$, with participants improving between time 1 and time 2, *M* (*SE*) = 85.42 % (0.91) and 88.58% (0.75), respectively. Further, there was a main effect of task, $F(1, 154) = 97.88$, $p < .001$, $\eta^2 = .39$, whereby performance was higher on the emotion discrimination task (M = 91.86%, SE = 0.56) than the emotion matching (M = 82.14%, SE = 1.03, $p < .001$). There was a main effect of age group, $F(2, 154) = 11.03$, $p < .001$, $\eta^2 = .13$, with planned repeated contrasts showing that the performance of the 6-year-olds did not significantly differ from the 8-year-olds (p =.357), but that the 8-year-olds performance was lower than 10-year-olds ($p = .001$). There was no main effect of sex, nor any significant interactions, all *ps* > .05.

Identity matching. There was a main effect of age group, $F(2, 154) = 12.27$, $p < .001$, $\eta_p^2 = .14$, where planned repeated contrasts showed that the performance of the 6-year-olds ($M = 55.28$, $SE = 1.86$) was lower than the 8-year-olds ($M = 61.04$, $SE = 1.83$, $p = .029$), and that the 8-year-olds performance was significantly lower than the 10-year-olds ($M = 67.43$, $SE = 1.62$, $p = .010$; see Figure 3). Contrary to expectations, there was no significant increase in performance over the one-year time span, $F(1, 154) = 2.71$, $p = .102$, $\eta_p^2 = .02$. There was no main effect of sex, nor any significant interactions, all *ps* > .05.

Laterality quotient. There were no significant main effects, all *F*s < 2.40, all *p*s ≥ .120. There was a significant three-way interaction of age group by emotion by time point, $F(4, 292) = 2.47$, $p = .045$, $\eta_p^2 = .033$. Simple effects analyses showed that it was only in the 8-year-olds group that laterality quotients for angry increased in strength from time 1 to time 2, $F(1, 46) = 9.24$, $p = .003$, $\eta_p^2 = .06$ (see Figure 4). In addition to the ANOVA findings, we completed one-sample t-tests to check if the laterality quotients for each emotion and age group at each time point was significantly different than 0 (indicating bias). We found that with the exception of the 6-year-olds' sad laterality quotient at time 1 ($p = .099$), all other laterality quotients were significantly greater than zero, all *p*s ≤ .002, indicating RH bias (for more information on the sample, see the online supplementary information, Table A).

As there was no main effect of emotion, for the regression analyses we have computed a combined laterality quotient (calculated as we did for each emotion) into one laterality quotient for time 1 (LQ_1) and one for time 2 (LQ_2). Additionally, we have computed a laterality change score ($LQ_{change} = LQ_2 – LQ_1$) for each participant so that we can assess the difference in the strength of lateralization of LQ_2 from LQ_1; the change scores here will allow us the ability to interpret findings with regards to the direction of change. Finally, we computed interaction terms for the laterality at time 1 and the laterality difference score with sex and with age to assess moderation.

Predicting time 2 performance

To assess what predicts time 2 performance, we used hierarchical regression analyses. Block 1 contained the variables known to be related to task performance at time 2 (sex, age group, and task performance at time 1). Block 2 included the LQ_1 predictor variables (LQ_1, and interaction terms with sex and age group). Block 3 included LQ_{change} predictors (LQ_{change}, and interaction terms with sex and age group) to explore developments in laterality and its role in predicting task performance one year after initial testing. Outliers as influential cases were examined for all Casewise Diagnostics > 2.5, whereby Cooks distance was calculated and examined for overall influence of each case on the model; where outliers were removed due to having substantially greater influence on the model, this is denoted in the associated regression table (see Tables 4 to 6). All assumptions for multiple regression analyses were checked, and were met. All bivariate correlations are shown in Table 1.

Note that we carried out four additional hierarchical regression analyses to check the concurrent relationships with FER performance (LQ_1 and interaction terms predicting time 1 FER, LQ_2 and interaction terms predicting time 2 FER). In each, only age group was a significant predictor (see the online supplementary information, Table B).

Emotion discrimination. Hierarchical multiple regression analyses (presented in Table 2) showed that block 1 was a significantly better model than chance. Importantly, when the LQ_1 predictors in block 2 were added to the model there was significant improvement in the model, with a further 10.8% of the variance explained. There was no significant improvement in the model when the LQ_{change} measures were added (block 3). The final model included the predictors in block two and was a significant model, $F(6, 143) = 6.57$, $p < .001$. In this model, we see that being older positively predicted emotion discrimination ability, as did performance at time 1. Further, children who were more strongly lateralized to the RH for emotion processing at time 1 were more likely to perform better at time 2. Interestingly, there was an interaction between LQ_1 and age.

To assess the moderating effect of age on LQ_1 to predict emotion discrimination at time 2 we conducted three hierarchical multiple regressions, one for each age group. Predictors in block 1 were sex and emotion discrimination scores at time 1, and in block two we added LQ_1. It was found that for the 6 year olds, in the final model only LQ_1 was a significant predictor, ß = 22.73, $t = 4.23$, $p < .001$, and the model was significantly better than chance, $F(3, 40) = 6.14$, $p = .002$, accounting for 31.5% of the variability in scores. For the 8 year olds, in the final model sex, emotion discrimination at time 1, and LQ_1 were each independent significant predictors of emotion discrimination at time 2, ß = 2.57, $t = 2.21$, $p = .032$, ß = 0.13, $t = 2.77$, $p = .008$, and ß = 6.224, $t = 2.30$, $p =.026$, respectively; the final model was significant, $F(3, 43) = 7.51$, $p < .001$, accounting for 34.4% of the variability in scores. For the 10 year olds, there were no significant predictors, although emotion discrimination at time 1 was approaching significance (p = .053), and no model was significantly better than chance, $F(2, 57) = 2.37$, $p = .103$.

Emotion matching. Hierarchical multiple regression analyses (presented in Table 3) showed that block 1 was a significantly better model than chance. Importantly, when the LQ_1 predictors were added to the model there was no significant improvement in the model. However, with the addition of the predictors relating to LQ_{change} there was improvement (approaching significance) in the model. The final model with all predictors was significantly better than chance, $F(9, 140) = 4.575$, $p < .001$, accounting for 22.7% of the variance. In this model, we see that performing better in emotion matching at time 1 positively predicted emotion matching performance at time 2. Further, children who had greater developments in terms of strength of lateralization towards the RH performed better at time 2.

Identity matching. Hierarchical multiple regression analyses (presented in Table 4) showed that block 1 was a significantly better model than chance, explaining 7.8% of the variance. Including the laterality measures from time 1, as well as the change in laterality measures, did not significantly improve the model. In the final model it is only age group that is a significant positive predictor of time 2 identity matching performance.

Predicting time 2 strength of lateralization

To assess if our three key tasks may predict LQ_2 (i.e., emotion discrimination, emotion matching, or identify matching scores at time 1), we used hierarchical regression analyses. Block 1 contained the variables that would be expected to be related to LQ_2 (sex, age group, and LQ_1). Block 2 included predictor variables that related to task performance at time 1 on the key three tasks and Block 3 included predictor variables that were the degree of change from time 1 to time 2 on the three key tasks (change scores were created for each DV using time 2 score minus time 1 score). All bivariate correlations are shown in Table 1.

Analyses showed that in the first block only LQ_1 was a significant predictor of LQ_2, ß = 0.56, $t = 6.37$, $p < .001$. Including task performance scores at time 1 and the performance change scores from time 1 to time 2 did not significantly improve the model. The final model, including block 1 only, was significantly better than chance, $F(3, 148) = 13.64$, $p < .001$, accounting for 21.7% of the variance. Note that there were no outliers that exerted undue influence in this particular analysis.

Discussion

This study explores the longitudinal links between patterns of laterality for emotion processing and facial emotion recognition (FER) ability. Consistent with previous research (e.g., Bruce et al., 2000; De Sonneville et al., 2002; Johnston et al., 2011; Kolb, Wilson, & Taylor, 1992), there was clear evidence that the younger age groups performed less well on each of the tasks in comparison to the older age groups, and that emotion task performance increased from initial testing. Importantly, beyond age, sex, and time 1 performance, the findings show that: 1) for the emotion discrimination task the predictive power of the model was significantly increased when strength of lateralization at time 1 was included; 2) for the emotion matching task the predictive power of the model was increased when the amount of change in strength of lateralization for emotion processing was included (i.e., becoming more strongly right hemisphere [RH] lateralized across the year predicted greater performance increases); 3) for the identity matching performance, the model was not improved with the addition of laterality predictors. Further, neither time 1 task performance for each of the three tasks, nor the changes in performance across the year, were predictive of time 2 strength of lateralization (beyond age group and time 1 lateralization). There are clear implications for the role of emotion lateralization in the development of FER abilities.

Developmental changes

As expected for all three performance tasks, performance was strongest in the oldest age group; while for the two FER tasks, but not the identity matching task, performance improved across the year of the study. Further, consistent with Bruce et al. (2000), children's performance was higher on the emotion discrimination task than the emotion matching task, supporting that the tasks differ in difficulty. For the lateralization of emotion processing task, consistent with Workman et al. (2006), we found no differences between the age groups, nor emotion types, supporting that lateralization patterns for emotion processing of these three emotions (happy, sad, angry) are established by 6 years. Further, only the 8- to 9-year-olds patterns of lateralization became more RH dominant when processing angry chimeras in the one year period; this is similar to Workman et al.'s finding that 10-year-olds were more strongly RH dominant for angry emotion processing than 5-year-olds .

Predicting performance

As expected, it was shown that lateralization played a role in predicting children's emotion task performance but not identity task performance, supporting the fact that the emotion CFT is specific to FER rather than facial recognition. Additionally, we found evidence that hemispheric laterality for emotion processing is linked to performance. These findings support the Boles et al. (2008) model that strength of lateralization for emotion processing is positively related to future task performance, but it is unclear why change in laterality for emotion processing only independently predicts emotion matching ability. We propose that laterality for emotion processing may have had differing relations with the two emotion tasks because our participants were RH lateralized for emotion processing at time 1 and had the appropriate processing capability for the emotion discrimination task.

The emotion discrimination task is an easier task than the emotion matching task (Bruce et al., 2000); emotion discrimination requires that children compare and match configural characteristics of a facial expression with the internal representation of a target emotion, while emotion matching may be more piecemeal where children may compare and match facial features and may be ‘distracted’ by less relevant or ambiguous features thereby imposing high demands on children (De Sonneville et al., 2002). Interestingly, laterality for emotion processing at time 1 predicted emotion discrimination performance at time 2 only for the two younger age groups not the 10-year-olds who had already, presumably, mastered the emotion discrimination task. When presented with an emotion task that they are not proficient at, or that is more challenging, it may be that children benefit from becoming more strongly specialized for emotion processing in the RH. To test this, it would be important to assess these links with children younger than 6 years old. We know that infants in the first two years develop the ability to recognize facial expressions of emotion (Nelson, 1987) and that 6- to 7-month-olds show hemispheric differences in their hemodynamic response within the temporal regions to happy (greater left temporal region activation) and angry (greater right temporal region activation) facial expressions (Nakato, Otsuka, Kanazawa, Yamaguchi, & Kakigi, 2011); yet, Barth and colleagues (2012) did not find a significant relation for a group of 49-

month-olds (40% of whole showed a pattern of RH dominance for emotion processing) between performance on the CFT and an emotion recognition task, indicating the relationship may be emerging between 4 and 6 years.

Another reason to explore these patterns with younger children is to understand when emotion processing becomes lateralized. While our findings are broadly consistent with Boles et al. (2008) model (positive relation between laterality for emotion processing and emotion recognition), they also predicted that emotion processing becomes lateralized later in childhood, which our findings do not support (become RH dominant earlier than they proposed). We have shown that 6-year-olds show RH dominance in the patterns of lateralization for emotion processing. Alternatively, we explored patterns of lateralization for emotion processing of earlier developing emotions than later developing emotions (see Workman et al., 2006); it may be that the Boles et al. model is more appropriate when we consider all six basic emotions.

This research highlights that there is a link between task difficulty, performance, and being more strongly RH dominant over time. These findings are consistent with evidence that for groups who may be less proficient at emotion recognition (e.g., younger children, males) that they may also be more strongly lateralized to the RH for emotion processing. In comparison to females, males are less proficient at recognizing emotions (McClure, 2000) and are more strongly RH dominant for emotion processing (e.g., Bourne, 2005). In fact, research shows that younger children (but not older children) and that boys (but not girls) who were more strongly lateralized for emotion processing had stronger performance on an emotion recognition task. Similarly, emotion recognition performance is impaired for those who are higher in social anxiety and depression (Bourke, Douglas, & Porter, 2010; Silvia et al., 2006; Simonian, Beidel, Turner, Berkes, & Long, 2001), and findings show that those who have higher fear of negative evaluation and males who use more negative emotion regulation strategies have stronger patterns of lateralization to the RH for facial emotion processing (Bourne & Watling, 2014). Therefore, there is converging evidence that at times when FER is weak, there is a benefit of being more strongly lateralized to the RH for emotion processing; longitudinal research is required to explore this with tasks that vary in difficulty (e.g., assessing FER with lower intensity images, varying stimuli presentation times).

Predicting lateralization of emotion processing

Whilst findings show that there was a relation between emotion lateralization and later emotion recognition, we did not find that time 2 strength of lateralization for emotion processing was predicted from either of the two emotion recognition tasks, the identity task, nor changes in task performance over the year. This suggests that it may be emotion lateralization that develops and influences later FER, rather than the other way around. This proposition is supported by Bourne and Gray (2009) who found that lateralization for emotion processing may be set very early on. They found that exposure to prenatal testosterone accounts for the variability in the strength of lateralization for emotion processing (positive relation), while exposure to hormones later in life through hormone replacement therapy did not influence laterality for emotion processing. However, it may also be that we did not find that the emotion recognition tasks, in particular, predicted lateralization for emotion processing due to their strength of RH lateralization for emotion processing at time 1. It would be important to explore these questions with younger children who are becoming increasingly RH lateralized for emotion processing.

Limitations

This study indicates that laterality plays a role in developing FER ability. However, it is important to recognize that this study used a behavioral task as a proxy measure to assess patterns of hemispheric lateralization for emotion processing. Whilst there is evidence that this task is a strong indicator of emotion processing in the brain, we need to better understand what is happening with processing in the brain. Future work using neuroimaging techniques is needed to assess if patterns of activation are lateralized when recognizing emotions, and if greater lateralization predicts differences in FER. Further, whilst our findings suggest that it may be that emotions are first lateralized for processing in the RH and this supports later FER skills, we are unable to address causality with the current design. Future longitudinal work (three points of data collection or more) with younger children would help establish if hemispheric specialization occurs alongside, before, or after FER skills develop.

Importantly, this work does not say anything about how experience may affect the relation. Research has shown that brain activation does change as a result of experience. For instance, Fu and colleagues (2008) found that patients during an acute depressive episode showed elevated amygdala-hippocampal activity when looking at sad faces in comparison to healthy controls, and this was reduced following cognitive-behavioral therapy. It is therefore important to understand how experience may impact the organization of the brain, specifically, hemispheric lateralization for emotion processing.

Summary

This work demonstrates that the strength of lateralization for facial emotion processing is related to future FER performance, highlighting that where FER skills are continuing to develop that increasing strength of RH lateralization plays an important role. However, it continues to be unclear the role of causality, which should be addressed in future research, alongside exploring these questions using neuroimaging techniques. These findings explain some of the individual differences that we see in FER; it would be important to understand how relations vary for groups with atypical development and to vary FER task difficulty so that we can gain a deeper understanding of the link between FER ability and emotion processing in the brain.

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Table 1. Bivariate correlations (N = 160)

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Age group	.10	.00	-.06	.25***	.25***	.24**	.20**	.32***	.25**	-.10	-.04	-.02
2. LQ_1		.46 ***	-.38***	.13	.24**	.16^{+}	.18*	.04	.03	.02	.02	.00
3. LQ_2			.64***	.03	.04	.02	.15+	.07	-.01	-.01	.11	-.06
4. LQ_{change}				-.07	-.12	-.10	.04	.05	.00	.00	.12	-.04
5. T1 Emotion discrimination					.25***	.38***	.19*	.09	.12	-.83***	-.18*	.03
6. T2 Emotion discrimination						.18*	.34***	.09	.13	.34***	.13	.04
7. T1 Emotion matching							.34***	.09	-.03	-.27***	-.60***	-.08
8. T2 Emotion matching								.01	.02	.01	.55***	.01
9. T1 Identity matching									. 14^{+}	-.04	-.08	-.57***
10. T2 Identity matching										-.04	.04	.73***
11. Emotion discrimination$_{change}$											.25 **	-.01
12. Emotion matching$_{change}$												.08
13. Identity matching$_{change}$												

$^{+}$ p < .10; * p < .05; ** p ≤ .01; *** p ≤ .001; T1 = time point 1, T2 = time point 2

Table 2. Regression analyses summary predicting time 2 emotion discrimination performance

		Predictor statistics			Block change statistics	
		β	t	p	Significance	R^2
Block 1	Sex	0.451	0.610	.543	*F*(3, 146) = 5.87,	.108
	Age group	0.336	1.460	.146	***p* = .001**	
	T1 Emotion Discrimination	0.115	3.396	**.001**		
Block 2	Sex	0.989	1.097	.275	*F*(3, 143) = 6.59,	.216
	Age group	0.812	2.913	**.004**	***p* < .001**	
	T1 Emotion Discrimination	0.096	2.964	**.004**		
	LQ_1	19.876	2.878	**.005**		
	LQ_1 * Sex	-1.942	0.581	.562		
	LQ_1* Age group	-3.227	2.996	**.003**		
Block 3	Sex	0.983	0.924	.357	*F*(3, 140) = 0.04,	.217
	Age group	0.795	2.638	**.009**	*p* = .991	
	T1 Emotion Discrimination	0.097	2.944	**.004**		
	LQ_1	18.826	2.382	**.019**		
	LQ_1 * Sex	-1.504	0.408	.684		
	LQ_1 * Age group	-3.144	2.548	**.012**		
	LQ_{change}	-2.076	0.230	.818		
	LQ_{change} * Sex	0.919	0.286	.776		
	LQ_{change} * Age group	0.052	0.054	.957		

Note: Sex (0 = male, 1 = female). Three cases had standardized residuals outside of +/- 2.5, two of which had Cook's distance > .10 and were removed from the analysis above; prior to removal only block 1 was significant with 13% of variance accounted for.

Table 3. Regression analyses summary predicting time 2 emotion matching performance

		Predictor statistics			Block change statistics	
		β	t	p	Significance	R^2
Block 1	Sex	3.690	1.769	.079	*F*(3, 146) =	.171
	Age group	1.086	1.660	.099	10.02, ***p* < .001**	
	T1 Emotion Matching	0.269	4.186	**<.001**		
Block 2	Sex	1.504	0.550	.583	*F*(3, 143) = 0.83,	.185
	Age group	1.122	1.304	.194	*p* = .479	
	T1 Emotion Matching	0.269	4.096	**<.001**		
	LQ_1	-15.319	0.727	.468		
	LQ_1 * Sex	13.566	1.348	.180		
	LQ_1 * Age group	-0.383	0.118	.906		
Block 3	Sex	3.083	1.083	.281	*F*(3, 140) = 2.56,	.227
	Age group	1.639	1.822	.071	*p* = .058	
	T1 Emotion Matching	0.276	4.265	**<.001**		
	LQ_1	7.635	0.333	.740		
	LQ_1 * Sex	6.605	0.614	.540		
	LQ_1 * Age group	-2.950	0.825	.411		
	LQ_{change}	56.959	2.195	**.030**		
	LQ_{change} * Sex	-14.064	1.507	.134		
	LQ_{change} * Age group	-3.133	1.139	.257		

Note: Sex (0 = male, 1 = female). Four cases had standardized residuals outside of +/- 2.5, two of which had Cook's distance > .10 and were removed from the analysis above; prior to removal only block 1 was significant with 15% of variance accounted for.

Table 4. Regression analyses summary predicting time 2 identity matching performance

		Predictor statistics			Block change statistics	
		β	t	p	Significance	R^2
Block 1	Sex	3.989	1.286	.200	*F*(3, 147) = 4.12,	.078
	Age group	2.886	2.872	**.005**	***p* = .008**	
	T1 Identity Matching	0.031	0.311	.756		
Block 2	Sex	6.276	1.580	.116	*F*(3, 144) = 1.49,	.105
	Age group	1.461	1.153	.251	*p* = .221	
	T1 Identity Matching	0.044	0.435	.665		
	LQ_1	-5.892	0.194	.847		
	LQ_1 * Sex	-12.857	0.863	.389		
	LQ_1 * Age group	8.833	1.746	.083		
Block 3	Sex	5.782	1.360	.176	*F*(3, 141) = 0.33,	.111
	Age group	1.145	0.856	.393	*p* = .807	
	T1 Identity Matching	0.019	0.184	.854		
	LQ_1	-15.265	0.445	.657		
	LQ_1 * Sex	-11.101	0.677	.499		
	LQ_1 * Age group	10.592	1.954	.053		
	LQ_{change}	-30.588	0.773	.441		
	LQ_{change} * Sex	-0.673	0.047	.962		
	LQ_{change}* Age group	3.980	0.931	.353		

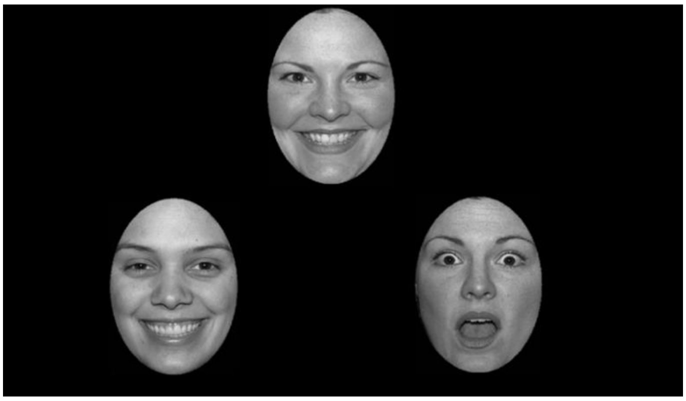
Note: Sex (0 = male, 1 = female). One case had standardized residuals outside of +/- 2.5 with Cook's distance > .10 and was removed from the analysis above; prior to removal only block 1 was significant with 7% of variance accounted for.

Figure 1. Chimeric face trial, with happy emotion shown in the left visual field (LVF) on the top face and in the right visual field (RVF) in the bottom face

Figure 2. Trial screen shots for each of the three performance tasks

a) Example of an emotion discrimination trial

b) Example of an emotion matching trial



c) Example of an identity matching trial

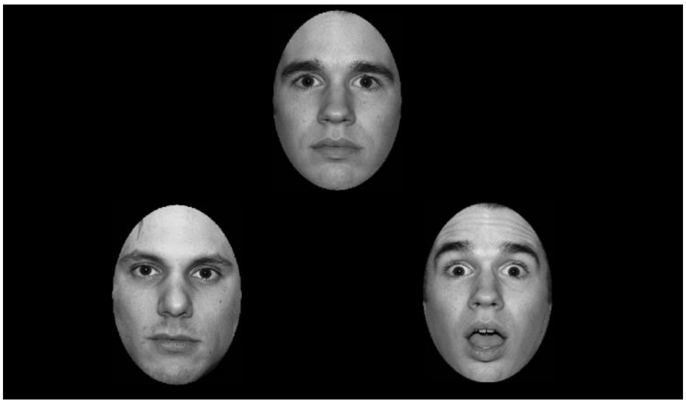


Figure 3: Mean (SE) of tasks performance (percentage correct) by age group and time point of visitation (initial [Time 1] and plus 12 months [Time 2])

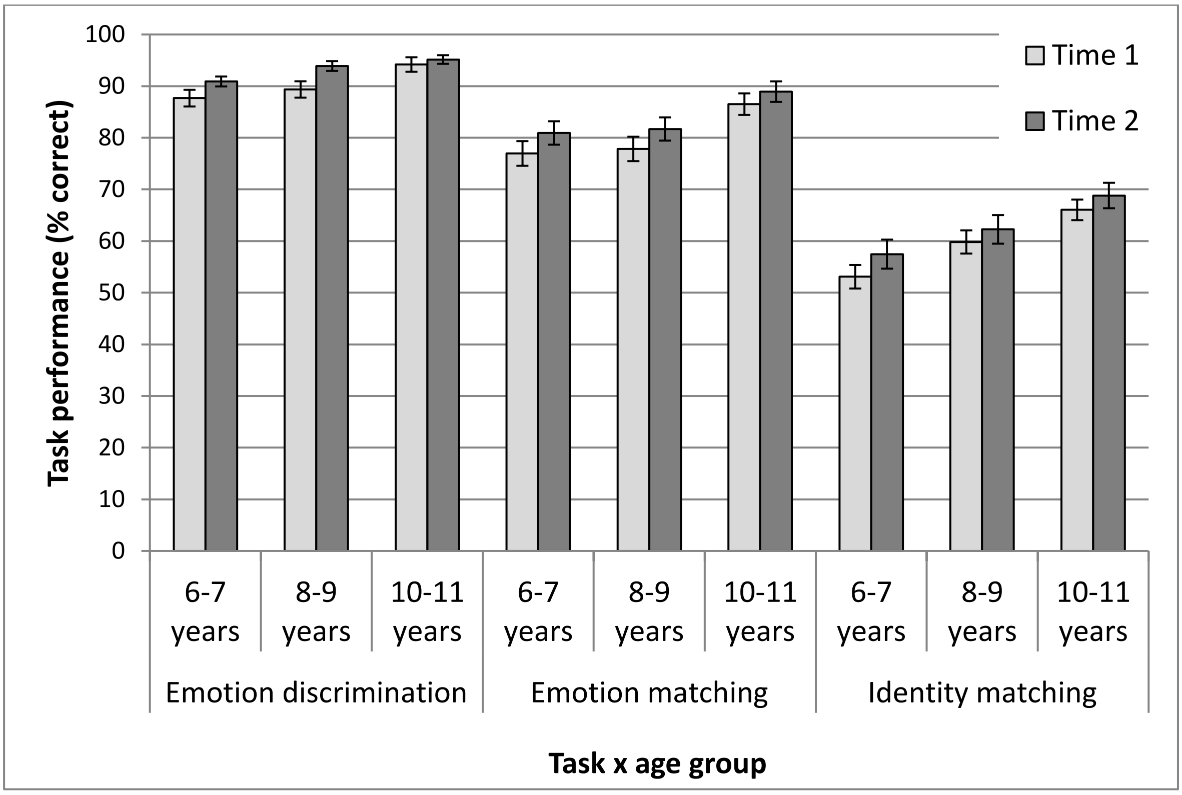


Figure 4. Mean (SE) of laterality quotients (LQ) for each emotion by age group, time point of visitation (initial and plus 12 months), and emotion