Children process the self face using configural and featural encoding: Evidence from eye tracking

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Abstract

Much is known about how the self-face is processed neurologically, however there has been little work exploring how self, familiar, and unfamiliar faces are viewed differently. Eye-movement data provides insights for how these stimuli are encoded and pupilometry provides information regarding the amount of effort put in when processing these stimuli. In this study, we utilise eye-tracking to explore differences in the encoding of self, age- and gender-matched personally familiar faces and age- and gender-matched unfamiliar faces in school-aged children. The self face was processed using more fixations than familiar and unfamiliar faces, specifically to the most diagnostic features, indicating enhanced and efficient use of featural processing. Furthermore, the self face was processed with more and longer central fixations than unfamiliar faces, indicating enhanced use of configural processing. Finally, the self face seemed to be processed the most efficiently as revealed through our pupilometry data. These results are incorporated into a model of self face processing that is based on efficient and robust processing consistent with the neurological data indicating that multiple brain areas are used to process faces.

Keywords

Eye-tracking; perceptual expertise; self face recognition; own-face; pupilometry; development; configural processing; featural processing; holistic processing

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People tend to process their own face differently from other faces (Ma & Han, 2010) due to its significance for the self concept and self awareness (Gallup, 1998). This differential processing results in faster responding to the self face when recognising faces compared to famous faces (Keenan, Wheeler, Gallup, & Pascual-Leone, 2000) and personally-familiar faces (Keenan, McCutcheon, Freund, Gallup, Sanders, & Pascal-Leone, 1999) or when searching for faces in a visual search task (Tong & Nakayama, 1999). This advantage for the self face is found irrespective of viewing angle (Tong & Nakayama, 1999, but see Troje & Kersten, 1999) and is present for upright and inverted faces (Keenan et al., 1999; Tong & Nakayama, 1999) despite expert face recognition being based on the correct orientation of faces (e.g., Carey & Diamond, 1977).

Given that humans can quickly and efficiently differentiate between many thousands of highly similar faces, face recognition is considered an expert visual ability. Expert face recognition is said to based on configural processing (Maurer, Le Grand, & Mondloch, 2002) though these concepts are only loosely defined[1]. This expert processing is selectively disrupted by inversion (e.g., Valentine, 1988; Edmunds & Lewis, 2007; Rossion, 2008) and is employed for processing familiar and unfamiliar faces (Scapinello & Yarmey, 1970; Yarmey, 1971). Superior self face processing compared to other face processing and the fact that it is not disrupted by inversion, indicates that the self face is processed uniquely or employing both expert and inexpert processing mechanisms effectively. The second assertion may seem at odds with the notion that some authors may consider featural and configural processing to be contrasting processing mechanisms. This study will establish whether the self face is processed uniquely and the precise relationship to featural and configural processing.

[1] Maurer et al. (2002) describe three forms of configural processing: processing of the first-order relational information (i.e., the basic arrangement of a faces); processing of second-order relational information (i.e., the individual spatial relations between the features in a face (Diamond & Carey, 1986); and holistic processing, in which the features of a face and their interrelations are processed as a gestalt (Rossion, 2008). These three processes are distinct and do not correlate with each other (Rezlescu, Susilo, Wimer, & Caramazza, 2017), yet many researchers use them interchangeably. Holistic processing is likely to be the basis for expertise with faces (Rossion, 2008).

There is evidence from neuroscience that the self face is processed in a special manner relative to other faces employing both expert configural processing and inexpert featural processing. Numerous neuroimaging studies have highlighted that there is a distributed right-hemisphere processing system for the self face compared to famous and stranger faces (Heinisch, Dinse, Tegenthoff, Juckel, & Brüne, 2011; Keenan, Nelson, O'Conner, Pascual-Leone, 2001; Platek, Keenan, Gallup Jr, Mohamed, 2004) and to personally familiar faces (Platek et al., 2006; Platek, Wathne, Tierney, & Thomson, 2008; Uddin, Kaplan, Molnar-Szakacs, Zaidel, & Iacoboni, 2005). While increased left hemisphere involvement has also been established (Kircher et al., 2001), this is primarily increased activation to the left fusiform gyrus (Devue, Collette, Balteau, Degueldre, Luxen, Maquet, & Brédart, 2007; Sugiura, Watanabe, Maeda, Matsue, Fukuda, & Kawashima, 2005) indicating that the self face occupies the perceptual and attentional system more completely than other faces because it is so important (Uddin et al., 2005). Gunji, Inagaki, Inoue, Takeshima, and Kaga (2008) have shown that an ERP associated with increased attention is found when children aged approximately 10.8 years process the self face (this is not present in children with pervasive developmental disorder known to affect self processing). Collectively, these results indicate that the self face is processed in a special way involving enhanced attention and potentially the involvement of the right and left fusiform gyrus. Given that the right hemisphere has been purported to process configurally (specifically, holistically) and the left hemisphere processes featurally (Rossion et al., 2000), these results indicate that the self-face may be processed both featurally and configurally. However, more direct tests of enhanced encoding of the self face involving both featural and configural processing have not been conducted.

One technique that has been recently used to explore how much holistic (and by extrapolation configural) and featural processing is employed is eye tracking (Chan & Ryan, 2012; Guo, 2012; Bombari, Mast, & Lobmaier 2009). Eye-movements represent the information that is being collected by the brain and therefore offer a strong line of evidence for what processing types may be occurring. While there is no one-to-one relationship between eye movements and attention, there has been strong evidence to show that featural processing (such as when viewing inverted faces) produces different eye movement patterns than holistic processing. Holistic processing is typically associated with longer central fixations (Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Hsiao & Cottrell, 2008; see also Miellet, Vizioli, He, Zhou, & Caldara, 2013): Each fixation is longer when processing holistically relative to featurally and these are usually to the top of the nose (between the eyes). Such fixations allow for the whole face to be sampled. Featural processing is associated with more shorter fixations to the centre of individual features (Bombari, et al., 2009). Therefore, featural processing is represented by more fixations (of shorter duration each) to more facial features than holistic processing. This pattern has been observed when participants view inverted faces (Hills, Cooper, & Pake, 2013; Van Belle, De Graef, Verfaille, Rossion, & Lefèvre, 2010) supporting the idea that inverted faces are processed featurally. This therefore suggests that eye movements offer a direct measure of holistic/configural and featural processing (Rossion, 2008).

In addition to eye movements, pupilometry can be used to explore how faces are coded. Pupilometry has been used widely as a measure of cognitive effort: when tasks are more difficult, pupils are wider (Polt, 1970; Porter, Troscianko, & Gilchrist, 2007) when participants are more engaged in a task, their pupils are wider (Fairclough, Moores, Ewing, & Roberts, 2009), and pupils are wider when more resources are devoted to a task (Van Der Meer, et al., 2010). This indicates that pupilometry can be a useful metric for exploring the depth with which faces are coded. Given the importance of the self face to the self concept, one would imagine that it would be processed with more effort and depth irrespective of whether the self face is processed configurally and/or featurally. By coupling eye movement information with pupilometry data, it will be possible to establish whether participants put more effort into coding their own face, or that they engage in both configural and featural processing. This allows for a greater understanding of the importance of the self face and how it is processed.

In the present study, we employed eye tracking to explore whether participants tend to view the self face differently to age- and gender-matched personally familiar and age- and gender-matched unfamiliar faces. We explore this effect in school-aged children in order to establish if there is any effect of development on self-face perception. Recently, it has been established that adult eye-movement patterns develop around the age of nine years of age, but this is earlier for familiar faces than unfamiliar faces (Hills, Willis, & Pake, 2013), therefore we assessed the performance of children aged 6 to 11 years in the present study. We also assess eye movements across upright and inverted faces, in order to confirm the use of featural coding when processing self faces. We hypothesise that there will be eye movement differences when viewing upright and inverted unfamiliar and personally familiar faces for our older participants, though less so for our younger participants. We expect the self face to be viewed using a mixture of configural and featural processing strategies revealed through more fixations to individual features and longer central fixations, Bombari et al., 2009). We also expect that the self face would be processed more deeply as indexed by pupilometry.

Method

Participants

Forty three (21 female) ethnically-White children aged between 6 years and 11 years 8 months old took part in this study. Participants were divided into two groups: the younger group (6 to 8.5 years; 13 female, mean age = 7.21 years) and the older group (8.6 to 11 years; 8 female, mean age = 10.02 years)[2]. Participants were recruited from a sample whose parents returned consent forms from two

[2] These age groups were chosen as they represent School Years 1-3 and Years 4-6 in the UK schooling system. Splitting by school age group has been shown to lead to more clear results in face recognition research (e.g., Hills, 2012), due to increased social interaction with these peers rather than those that are strictly own-age and social interaction has been determined to be important in various face recognition biases (Sporer, 2001). Furthermore, the magnitude of the FIE either increases up to age 9 years according to de Haan et al. (2009) before plateauing or is not present prior to the age of 9 years (Hills & Lewis, 2018). Furthermore, there appears to be a change in the recruitment of the fusiform gyrus (Aylward et al., 2005), the presentation of the

local schools. All participants were considered typically developing by their schools and their parents reported that they had normal or corrected vision.

Design

We employed a 2 x 2 x 3 x 5 mixed design with the between-subjects factor of participant age and the within-subjects factors of facial orientation (upright and inverted), facial familiarity (unfamiliar, personally familiar, and self-face), and facial feature (eyes, nose, mouth, forehead and hair, and chin and cheeks). We measured participants' eye movements when looking at the faces, recording the number of fixations and the mean length of each fixation to each feature. We also recorded pupil width as a measure of effort employed during encoding.

Materials

Photographs of all the children were taken from the same distance (120 cm) using the same camera against the same plain white background with the same lighting conditions. All faces displayed a happy-neutral expression and no extraneous features (such as clothing). Any differences in luminance or contrast was corrected using Matlab, backgrounds removed, and size standardised (size: 428 × 368 pixels, subtending to an approximate visual angle of $10.19^{\circ} \times 9.86^{\circ}$, with the resolution 72 dpi) offline in Photoshop. An inverted version of each face was created by rotating each face by 180°. Five areas of interest (AOIs, similar to Goldinger, He, & Papesh, 2009) were mapped out offline onto each face that corresponded to the features: eyes, nose, mouth, forehead and hair, and chin and cheeks (see Figure 1).

N170 (Itier & Taylor, 2004; Kuefner, De Heering, Jacques, Palmero-Soler, & Rossion, 2010), the demonstration of face specific eye movements (Hills et al., 2013) between the ages of 8 and 11 years.

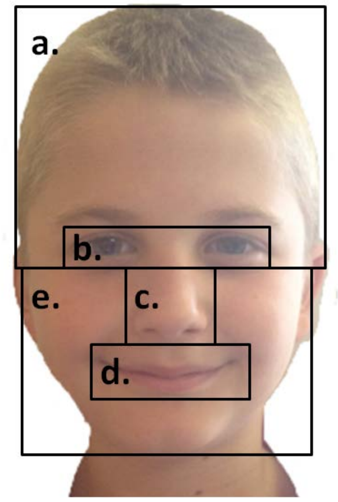

Figure 1. An example face stimulus used in the study with the AOIs mapped onto it: a) Forehead and hair; b) eyes; c) nose; d) mouth; and e) chin, cheeks, and ears. Note that the AOI boundaries were not visible to the participants.

For each self face, an age- and gender-matched face was chosen from the same class as the child to be the familiar face. Children would therefore have interacted with the familiar face every school day for at least two years. A research assistant also matched these faces visually for hair colour and distinctiveness. The unfamiliar face was matched in the same way to the self face, but was selected from the second school and therefore was unfamiliar to the participant (this was verbally checked during the experiment). There were, therefore, six types of faces: upright and inverted versions of the self, familiar, and unfamiliar faces and two photographs of each.

The faces were displayed on a white background, in the centre of a 15” (1280 × 800 pixels) LCD colour monitor, using ClearView v2.7.0. Eye movements were recorded using a Tobii X50 eye-tracker (Falls Church, VA), with embedded infrared cameras with a sampling rate of 50Hz. The eye-tracker was positioned in front of the laptop, under the screen, 60 cm from the participant. A fixation was defined as the eyes remaining in the same 30 pixel area for 100 ms (see Goldinger et al*.,* 2009). If the eyes left the region, but returned within 100 ms, it was considered to be the same gaze. These settings were based on the defaults for the Tobii eye-tracker.

Procedure

All participants were tested individually in a quiet and non-distracting environment in their school with a teacher present. The experimenter operated the computer (including all participant key presses), but was blind to what the screen displayed in order to prevent demand characteristics (see Hills, 2014). This also ensured that the participants fully engaged with the task by giving verbal responses and remaining as still as possible in order to record accurate eye-movement data. Verbal responses also deal with the issue that the self face advantage is larger if participants respond with their left hand (Keenan et al., 2001).

Participants first gave informed assent and then were seated 60 cm away from the front of the computer screen. Participants eyes were then calibrated to the eye tracker. This involved following a small blue ball around to nine pseudorandom locations on the screen. All participants eyes were calibrated on the first or second attempt. Participants were then presented with two series of the 12 faces. The faces were presented in a random order in both presentations. In the first presentation, participants rated the faces for how weird looking they were. In the second presentation, they stated if they recognised any of the faces by verbally saying "yes" or "no." Participants were 100% accurate at this task. Faces were on screen for 2 seconds each. Participants responded within this time. Between each face there was a blank screen. Participants were required to focus on the centre of the screen for 150 ms before the next trial began. Following the last face, the experiment was completed.

Results

In order to address our hypotheses, we first ran an analysis on number of fixations as this would reveal the involvement of featural coding: featural coding would be revealed through more fixations spread over more features (Blais, et al., 2008; Hsiao & Cottrell, 2008; Miellet, et al., 2013). Secondly, we explored fixation length to assess how much information could be extracted at each fixation as a measure of holistic coding: holistic coding would be revealed through longer fixations (directed between the eyes, Hills, et al., 2013; Van Belle, et al., 2010). As a direct measure of effortful encoding (Goldinger et al., 2009; Porter et al., 2007), we measured pupil width. Finally, we ran an analysis exploring how fixation patterns change with age.

Number of Fixations

We employed an analytical procedure similar to Bindemann, Scheepers, and Burton (2009) in order to deal with the fact that the AOIs were of different sizes. We calculated area-normalised scores by dividing the proportion of fixations each feature received by the proportion of the screen the feature occupied per trial. This transformation equates the size of each feature so that a score of one indicates the feature is scanned at random whereas a score significantly higher than one indicates that the region is specifically scanned (Fletcher-Watson, Findlay, Leekam, & Benson, 2008). An analysis on the raw data revealed a similar pattern of results for the internal features. For all analyses involving the variable 'feature', Mauchley's test of sphericity was significant, therefore we applied the Huynh-Feldt correction to the degrees of freedom.

Mean area-normalised number of fixations to each feature are summarised in Figure 2. These data were subjected to a 2 x 2 x 3 x 5 mixed ANOVA with the factors: participant age; face orientation; face type; and feature. We found a main effect of face type, $F(2, 82) = 5.15$, $MSE = 17.65$, $p = .008$, $\eta_p^2 = .11$. More fixations (indicative of increased featural processing) were made to self faces than to unfamiliar faces ($p = .009$). This main effect interacted with feature, $F(5.05, 207.07) = 3.55$, $MSE = 164.47$, $p = .004$, $\eta_p^2 = .08$. Šidák-corrected comparisons revealed that for self and familiar faces the nose (the most central feature) was fixated upon more often than the mouth and eyes (all ps < .05), but for unfamiliar faces, the eyes, nose, and mouth were fixated upon a statistically equivalent amount.

In order to confirm the reliability of the current data, we ensured that effects previously found to be reliable were replicated: we demonstrated a significant main effect of feature, $F(2.53, 103.68) = 112.92$, $MSE = 170.54$, $p < .001$, $\eta_p^2 = .73$. We replicated the hierarchy of features (e.g., Haig, 1985; Henderson, Williams, & Falk, 2005) showing that the internal features received significantly more fixation than the external features (all *p*s < .01). Confirming the notion that featural coding will be revealed through an increased number of fixations made to inverted faces than upright faces, we found a main effect of face orientation, $F(1, 41) = 138.04$, $MSE = 32.64$, $p < .001$, $\eta_p^2 = .77$. Replicating Hills et al (2012; 2013), we found that this interacted with feature, $F(2.49, 101.90) = 24.86$, $MSE = 253.58$, $p < .001$, $\eta_p^2 = .38$, such that the mouth received more fixations in inverted faces than upright faces ($p < .001$) and the eyes received more fixations in upright faces than inverted faces ($p = .05$). Replicating Hills et al. (2013), we found that orientation also interacted with participant age, $F(1, 41) = 9.63$, $MSE = 32.64$, $p = .003$, $\eta_p^2 = .19$. Older participants made more fixations to inverted faces (indicating featural processing) than to upright faces ($p < .01$), however for younger participants this difference was not significant. Furthermore, there was a three-way interaction between participant age, orientation, and feature, $F(2.49, 101.90) = 5.95$, $MSE = 253.58$, $p = .002$, $\eta_p^2 = .13$. This three way interaction was revealed through a larger significant two-way interaction between orientation and feature (as described above) for the older participants ($p < .001$) than for the younger participants ($p = .01$).

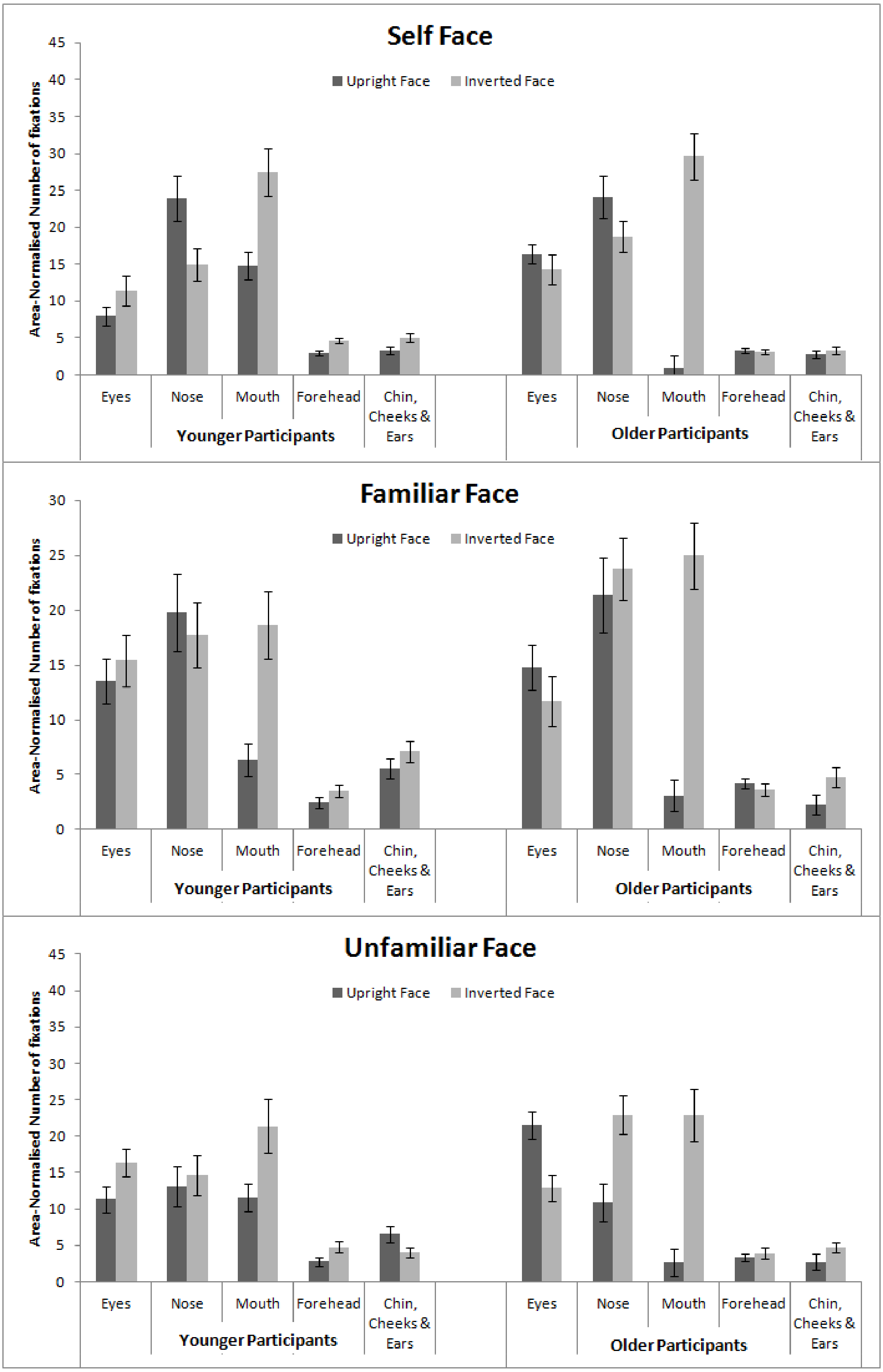

Figure 2. Mean area-normalised fixation count to each feature for upright and inverted faces for younger participants (left panels) and older participants (right panels) when viewing self (top panel), familiar (middle panel), and unfamiliar faces (bottom panel). Error bars represent standard error of the mean.

Fixation Length

Mean fixation length for each feature, summarised in Figure 3, was subjected to a parallel ANOVA. This analysis revealed an interaction between face type and feature, $F(4.58, 187.92) = 2.43$, MSE = 407.19, $p = .042$, $\eta_p^2 = .06$. Šidák-corrected comparisons revealed that for self faces, the average fixation to the eyes was longer than for the nose and mouth (ps < .05). This was not observed for familiar or personally familiar faces (ps > .1). This suggests longer central fixations and therefore holistic processing for self faces than familiar and unfamiliar faces.

There effect of orientation interacted with feature, $F(1.98, 81.03) = 14.28$, MSE = 593.62, $p < .001$, $\eta_p^2 = .26$. Šidák-corrected comparisons revealed that fixations were, on average, longer to the eyes than to all other features for upright faces (ps < .01), but there was no significant difference in fixation length for the eyes, nose, and mouth (ps > .50), but all were greater than the forehead and chin, cheeks, and ears in inverted faces, indicating a holistic encoding strategy being employed for upright faces more so than inverted faces. The main effect of feature was significant, $F(2.62, 107.31) = 46.28$, MSE = 325.15 $p < .001$, $\eta_p^2 = .53$, revealed through longer average fixations to the eyes than all other features (ps < .001).

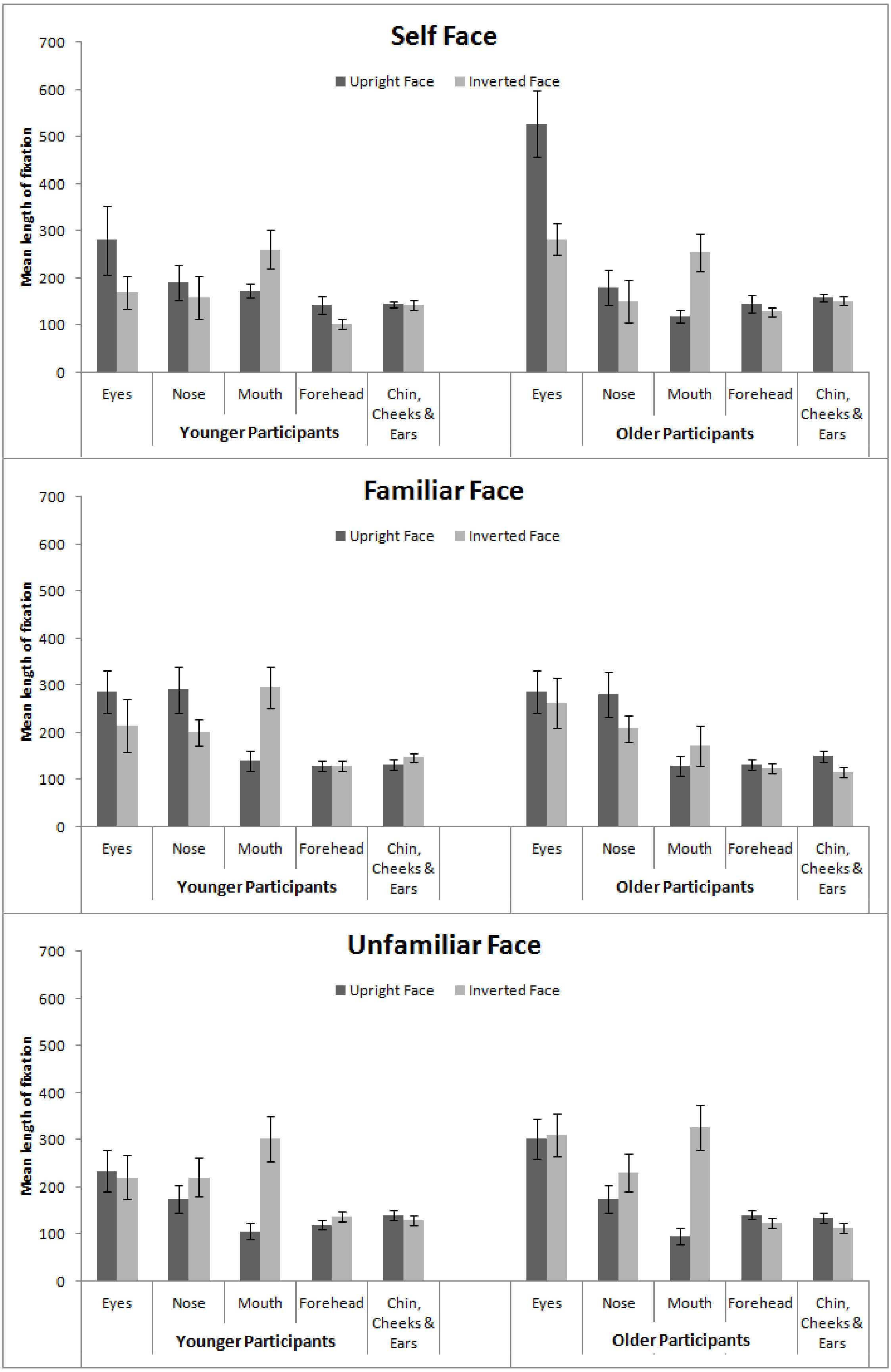

Figure 3. Mean fixation length (*ms*) to each feature for upright and inverted faces for younger participants (left panels) and older participants (right panels) when viewing self (top panel), familiar (middle panel), or unfamiliar faces (bottom panel). Error bars represent standard error of the mean.

Pupilometry

We employed a similar analysis protocol on the pupil width data, summarised in Figure 4, except that we excluded the feature variable as the largest effect driving pupil width is luminance (Porter et al., 2007) and luminance is different across features and this cannot be controlled for[3]. Therefore, the data were subjected to a 2 x 2 x 3 mixed-subjects ANOVA with the factors participant age, face orientation, and face type. This analysis revealed a main effect of face type, $F(2, 82) = 45.72$, MSE = 0.10, $p < .001$, $\eta_p^2 = .53$, in which pupil width was narrower when viewing self faces (M = 5.24 mm, SE = 0.07) compared to familiar faces (M = 5.65 mm, SE = 0.08) and unfamiliar faces (M = 5.65 mm, SE = 0.07). Consistent with prior research, younger participants' pupil width (M = 5.68 mm, SE = 0.09) was wider than older participants' (M = 5.35 mm, SE = 0.09), $F(1, 41) = 6.92$, MSE = 1.00, $p = .012$, $\eta_p^2 = .14$. These effects interacted, $F(2, 82) = 8.65$, MSE = 0.11, $p < .001$, $\eta_p^2 = .17$. Šidák-corrected comparisons revealed that the effect of face type was only significant for older participants (pupil

[3] Because participants view features of different faces different amounts, it is possible that the luminance of different features of these faces may influence the overall pattern of the pupilometry results rather than the effort engaged in processing them: If there are differences in the time spent looking at different features in the different types faces this might effect the pupilomentry. In order to rule this out, we explored the amount of time spent viewing each feature and the relative luminance value of each feature. We measured luminance using MatLab R2015 (Mathworks). By multiplying the time spent viewing each feature by the relative luminance of each feature, we established the predicted relative width of pupils for each type of face (and orientation). This is presented in Figure F1. This pattern is clearly different to those obtained by the data.

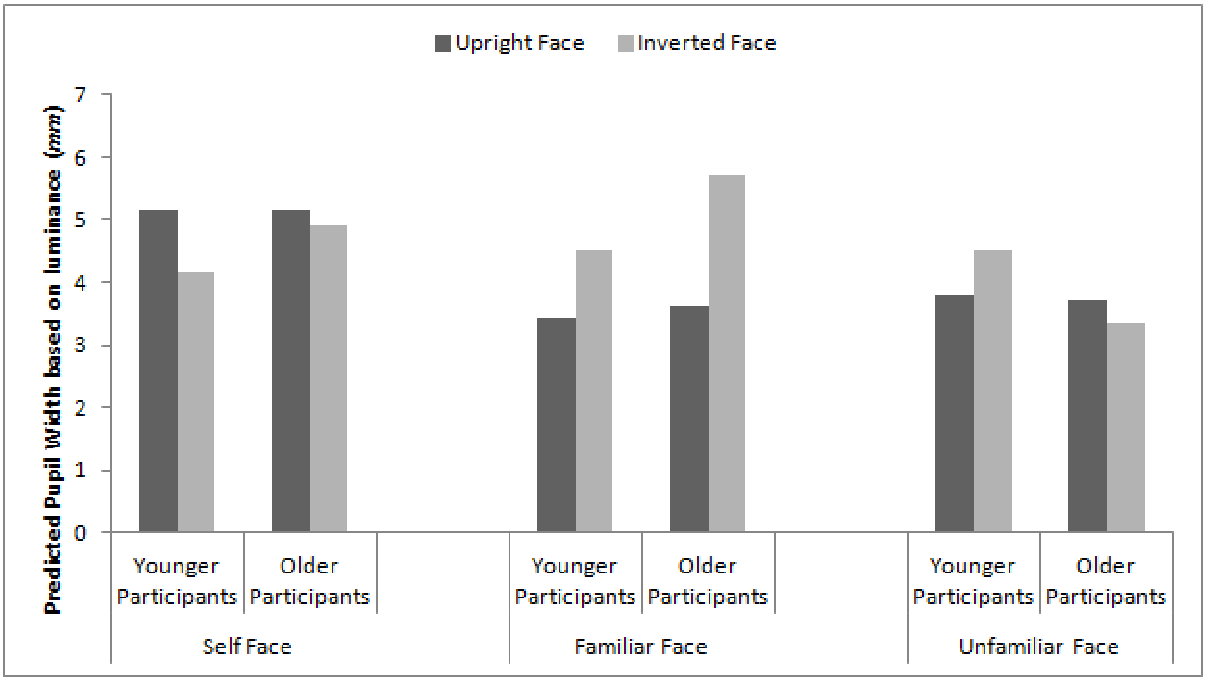

Figure F1. Predicted pupil width (*mm*) based feature luminance and time spent viewing each feature.

width was narrower when viewing self faces (M = 4.96, SE = 0.08) compared to familiar faces (M = 5.55 mm, SE = 0.11) and unfamiliar faces (M = 5.54 mm, SE = 0.10), ps<.01) and not for younger participants (all ps>.85).

The main effect of face type also interacted with face orientation, $F(1.47, 60.42$[4]$) = 8.79$, $MSE = 0.22$, $p = .001$, $\eta_p^2 = .18$. Šidák-corrected comparisons revealed that pupil width was narrower when viewing inverted self faces (M = 5.10 mm, SE = 0.06) than upright self faces (M = 5.38 mm, SE = 0.10, $p < .05$), but the effect of orientation was not present for familiar and unfamiliar faces. This interaction was only present for the older participants ($p < .001$) and not for the younger participants ($p > .45$), as revealed by a significant three-way interaction, $F(1.47, 60.42) = 7.37$, MSE = 0.22, $p = .003$, $\eta_p^2 = .15$.

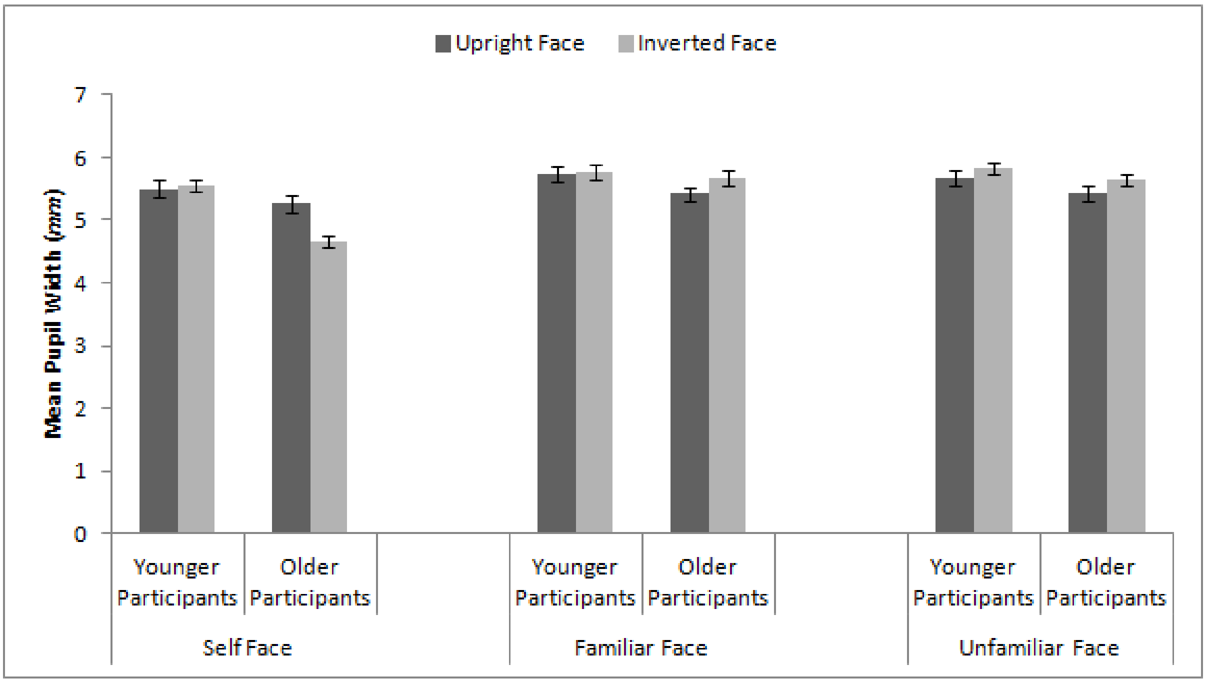

Figure 4. Mean pupil width (mm) when viewing upright and inverted faces self, familiar, or unfamiliar faces for younger participants and older participants. Error bars represent standard error of the mean.

[4] Mauchley's test of sphericity was significant for the face type by orientation effects, therefore we applied the Huyhn-Feldt correction.

Fixation pattern changes with age

White adults tend to fixate on the eyes more than any other feature (Althoff & Cohen, 1999; Henderson et al., 2005; Hills & Pake, 2013). Research has indicated a developmental trend toward adult-like fixations patterns (Kelly, Liu, Rodger, Miellet, Ge, & Caldara, 2011; Liu et al., 2013). Therefore, we would predict that the amount of eye fixation number and length (indexing holistic processing) in upright faces would increase with development. However, as the adult-like scan pattern appears for familiar faces before unfamiliar faces (Hills et al., 2013), therefore this pattern should be observed for unfamiliar faces and not familiar faces. Our previous analyses indicate that the self face may be more familiar and therefore should show the same effect as familiar faces.

To test this assertion, we ran a series of correlations between amount of fixation to each feature and participant age split by type of face. The pattern of correlations is presented in Table 1. These Šidák-corrected correlations reveal that age correlated with fixation toward the eyes in upright faces for unfamiliar faces, $r(41) = .42$, $p = .014$, and self faces, $r(41) = .48$, $p = .005$, but not familiar faces $r(41) = .03$, $p = .861$, contrary to our hypothesis. Similarly, holistic processing, indexed by longer fixation length to the eyes correlated with age in upright faces for unfamiliar faces, $r(41) = .45$, $p = .002$, and self faces, $r(41) = .38$, $p = .013$, but not familiar faces $r(41) = .09$, $p = .577$.

Table 1.

Correlation coefficients and uncorrected significance levels between age and time spent fixating on each feature and mean fixation duration at each feature split by type and orientation of face. Significant correlations following a Šidák correction are flagged with an asterix.

		Face Type and Orientation					
		Self face		**Familiar Face**		**Unfamiliar Face**	
		Upright	*Inverted*	*Upright*	*Inverted*	*Upright*	*Inverted*
Fixation Amount	*Eyes*	r = .48*, p = .005	r = -.28, p = .122	r = .03, p = .861	r = -.25, p = .159	r = .42*, p = .014	r = -.26, p = .138
	Nose	r = -.13, p = .470	r = -.50*, p = .003	r = -.30, p = .087	r = -.13, p = .473	r = -.12, p = .494	r = .16, p = .369
	Mouth	r = -.33, p = .063	r = -.36, p = .038	r = -.29, p = .103	r = .18, p = .312	r = -.28, p = .109	r = -.01, p = .977
	Forehead	r = .20, p = .272	r = -.04, p = .815	r = .39, p = .024	r = -.24, p = .175	r = .25, p = .166	r = -.31, p = .077
	Chin	r = -.28, p = .080	r = .48*, p = .005	r = -.23, p = .192	r = .31, p = .078	r = -.31 p = .076	r = .42*, p = .016
Fixation Duration	*Eyes*	r = .45*, p = .002	r = -.02, p = .905	r = .09, p = .577	r = -.02, p = .892	r = .38*, p = .013	r = -.07, p = .640
	Nose	r = -.27, p = .075	r = -.07, p = .643	r = .07, p = .658	r = .32, p = .034	r = -.05 p = .733	r = .10, p = .529
	Mouth	r = -.40*, p = .007	r = -.31, p = .042	r = -.10, p = .528	r = -.17, p = .284	r = -.04, p = .816	r = .08, p = .617
	Forehead	r = -.34, p = .027	r =.03, p = .859	r = -.19, p = .225	r = -.18, p = .254	r = .01, p = .959	r = -.30, p = .053
	Chin	r = .35, p = .023	r = -.21, p = .171	r = .12, p = .445	r = .18, p = .245	r = -.18 p = .252	r = -.08, p = .628

Discussion

The self face received more fixations than familiar and unfamiliar faces. More fixations is indicative of featural processing, according to Rossion (2008). This indicates that the self face is processed more featurally than both familiar and unfamiliar faces. Our results also indicate that there is no difference in the amount of featural coding employed for familiar and unfamiliar faces, consistent with evidence indicating that both types of faces are equally affected by disruptions to configural coding (i.e., inversion; Scapinello & Yarmey, 1970; Yarmey, 1971). Consistently, our results indicated that participants had longer individual fixations to the eyes for the self face compared to familiar and unfamiliar faces suggesting they were extracting more information from the eyes. This indicates enhanced coding of the eyes, indicating that the featural encoding engaged in is enhanced because the eyes are the most diagnostic feature for recognising White faces (Hills, Ross, & Lewis, 2011). These results suggest that the self face received enhanced (featural) processing due to its importance because the most diagnostic feature was viewed.

Both self and familiar faces received more fixations to the centre of the face, which is typically indicative of holistic processing, than unfamiliar faces. We interpret this as more configural coding (as holistic processing is a type of configural coding, Maurer et al., 2002) was employed for self and familiar faces relative to unfamiliar faces. Therefore, the self face benefits from increased use of configural coding. Given the relationship between configural and specifically holistic processing and expert face recognition (Richler, Cheung, & Gauthier, 2011), this result suggests that the expert processing mechanisms were utilised for processing the self face more so than unfamiliar faces. The self face therefore benefits from more efficient coding and memory, highlighting its psychological importance.

These data indicate that the self face is so important or so frequently viewed, that it is processed using a unique combination of highly efficient featural coding *and* expert configural coding. Familiar faces, however, are primarily processed in an expert configural manner and unfamiliar faces, were processed using less efficient featural processing. The self face, which is viewed daily (in the mirror, for example) and holds a special place in the self concept (Gallup, 1998), is processed efficiently using both processing types. These data also highlight how face recognition more generally is supported by both featural and configural processing (Schwaninger, Lobmaier, & Collishaw, 2002) and that both can be employed when the appropriate task demands are present.

The pupilometry data revealed that self faces were processed with the least effort as indicated by the narrowest pupils when viewing self faces. This is consistent with evidence from Gobbini & Haxby (2006) who indicate that the more familiar someone is with a face, the less effort is required to process it. This highlights that the self face is processed in a highly efficient manner. We found that this effect was only present for our older participants. We interpret this as either that the children required more familiarity with the self face for it to be processed with less effort than afforded by eight years eight months. Alternatively, the self face may not be considered as special to younger participants and there is development in the processing of the self face, with it becoming more easily processed with increasing age. This may relate to the development of the self concept (Sebastian, Burnett, & Blakemore, 2008) that occurs in parallel to cognitive development (Marshall, 1989). Such a finding is consistent with other data on the coherence of the self-concept. It is more coherent at an older age, leading to easier comparisons with others based on the self (Choudhury, Blakemore, & Charman, 2006).

In order to assess the development of how faces are processed, we ran correlations between the amount of fixation to each feature and age. These revealed that for unfamiliar and self faces, age correlated with the amount of eye fixation, whereas for familiar faces, it did not. We explain this finding as the scan pattern when viewing faces becoming more refined and adult-like with age, similar to results shown by Kelly et al. (2011) and Liu et al. (2013). This refinement is not needed for familiar faces as these are already processed in a more adult-like manner, as revealed by significant inversion effects for familiar faces occurring earlier in development than for unfamiliar faces (Hills et al., 2013). The rather more surprising result here is that the amount of eye fixation correlated with age for self faces. We interpret this with a developmental improvement in the ability to extract information from the eyes and therefore improving featural coding from these diagnostic features. In other words, there is an enhancement in featural coding associated with age alongside the apparent improvement in configural coding (de Heering, Rossion, & Maurer, 2012).

Taken together, these findings reveal a pattern of processing for self faces that is characterised by enhanced configural *and* efficient featural coding. While this may seem unusual, given that classically these types of processing are considered as being opposite, recent neuroscientific evidence suggests it should indeed be possible: the right hemisphere is employed for configural processing and the left hemisphere is recruited for featural processing (Rossion et al., 2000). Therefore, if both hemispheres are recruited, then both types of processing should be possible.

This enhanced configural and featural coding should imply that processing the self face is not detrimentally affected by inversion, as shown by Keenan et al. (2001) and Tong and Nakayama (1999). We also observed that the self face requires less effort to process than familiar and unfamiliar faces because it occupies the attention system so easily (Gunji et al., 2008; Uddin et al., 2005). This highlights that processing the self face is efficient and robust (i.e., it can be processed using multiple mechanisms). Indeed, we found that the inverted self face was processed with less effort than the upright self face. This suggests that the self face occupies such an important role that it can be processed efficiently even when inverted. Indeed, the data suggests it can be processed more efficiently than the upright self face, potentially due to the highly efficient featural coding afforded to the self face (as revealed by the eye movement data). Such results are entirely consistent with the brain imaging data showing a distributed network of brain regions involved in processing self faces in the right hemisphere (Heinisch et al., 2011; Keenan et al., 2001; Platek et al., 2004, 2006, 2008; Uddin et al., 2005) but also employing left hemisphere networks including the left fusiform gyrus (Devue et al., 2007; Sugiura et al., 2005). We have also shown that there is some development in the processing of the self face from six- to 12-years of age, however this may be limited to enhancing featural coding. Further research could address the development of self face processing further: the current eye-tracking methodology could easily be applied to younger children to investigate when the self face becomes uniquely processed.

While our results speak specifically to self-face processing, we have also replicated and extended findings on face processing more generally. Specifically, that orientation affects how faces are encoded. This was revealed through eye movement differences for upright and inverted faces: decreased eye scanning and increased mouth scanning with less information extracted at each fixation was observed for inverted faces relative to upright faces. Crucially for models of face recognition development, this effect was found only for participants who were older than eight years eight months old.

These results are entirely consistent with a developmental model of face recognition in which expert mechanisms, as measured by the face-inversion effect, are revealed at approximately nine-years of age (Carey & Diamond, 1977; Hills & Lewis, 2018). Indeed, brain responses associated with expert face recogition (enhanced activation of the fusiform gyrus for upright faces, Kanwisher, McDermott, & Chun, 1997, but not inverted faces, Kanwisher, Tong, & Nakayama, 1999) are not present in children eight-years old and younger (Aylward, et al., 2005; Joseph, Gathers, Liu, Corbly, Whitaker, & Bhatt, 2006). Furthermore, the ERP N170 (thought to be 'face specific' Bentin Allison, Puce, Perez, & McCarthy, 1996) is delayed in 8-year old children compared to 9-year old children (Itier & Taylor, 2004) which is a similar result to that observed in adults when viewing inverted faces. This may reflect a delay in employing expert processing or categorisation, as the delay in N170 is not specific to faces (Kuefner et al., 2010). These results indicate that prior to age 10, children do indeed process faces qualitatively differently to adults. That is not to say that children cannot engage in some forms of configural and holistic processing as measured by various tasks (e.g., the parts and wholes test, Pellicano & Rhodes 2003). However, configural or holistic processing as revealed by these tasks may be unrelated to that of the face inversion effect (Rezlescu et al., 2017). Furthermore, holistic processing in children may occur through different processing (and certainly eye movement, brain regions, and brain activity) than would be observed in adults. In other words, there may be different strategies that lead to the same behaviour.

We have highlighted here how faces of different levels of familiarity are processed differently. This has important implications for models explaining the development of face recognition generally. Most models do not elucidate differential development in the processing of different types of faces (e.g., Crookes & McKone, 2009). While models of development of face processing suggest that face memory develops later than face perception (Weigelt, Koldewyn, Dilks, Bala, McKone, & Kanwisher, 2013), our data suggest that face perception is more developed for self and familiar faces than for unfamiliar faces at age 10 years. This indicates that there may be further development to how faces are encoded with development into adolecence, presumably linked to eye movement control development (Luna, Velanova, & Geier, 2008). This develops first for faces more frequently encountered before being applied to all faces. Models of face recognition development should therefore be developed to account for these data.

In conclusion, we have shown, using eye tracking, that the self face is processed both configurally and featurally by school aged children. This conveys an advantage to the processing of the self face such that it requires less effort to process. We have also shown that there is some development in the processing of the self face revealed through correlations of eye fixation with age. These results have been explained in terms of more efficient and robust coding for the self face.

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