



## PAPER

# Fitting the child's mind to the world: adaptive norm-based coding of facial identity in 8-year-olds

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## Abstract

*In adults, facial identity is coded by opponent processes relative to an average face or norm, as evidenced by the face identity aftereffect: adapting to a face biases perception towards the opposite identity, so that a previously neutral face (e.g. the average) resembles the identity of the computationally opposite face. We investigated whether children as young as 8 use adaptive norm-based coding to represent faces, a question of interest because 8-year-olds are less accurate than adults at recognizing faces and do not show the adult neural markers of face expertise. We found comparable face identity aftereffects in 8-year-olds and adults: perception of identity in both groups shifted in the direction predicted by norm-based coding. This finding suggests that, by 8 years of age, the adaptive computational mechanisms used to code facial identity are like those of adults and hence that children's immaturities in face processing arise from another source.*

## Introduction

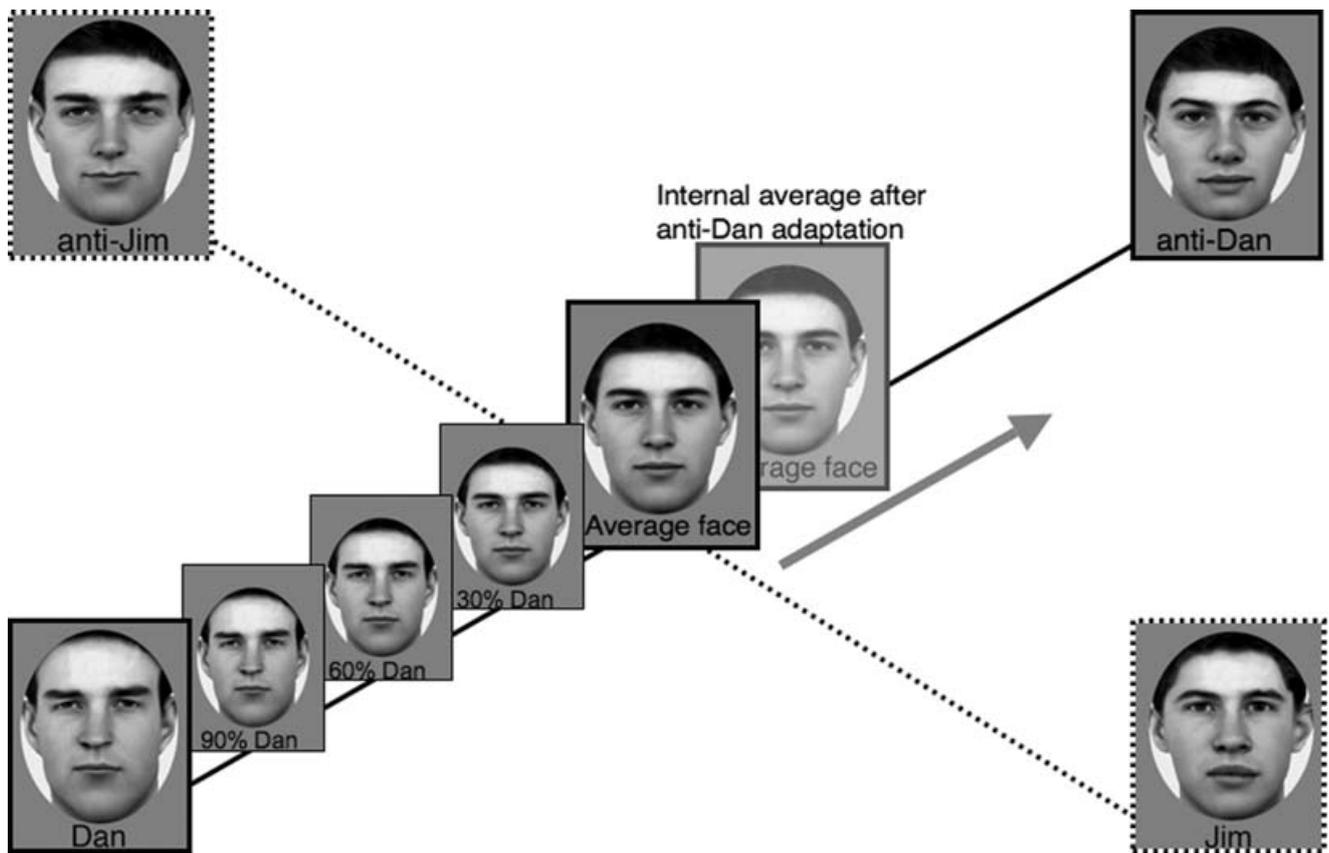
Several lines of evidence suggest that adults represent faces in a multi-dimensional face-space centered on an average face or norm (Rhodes, Brennan & Carey, 1987; Rhodes, Jeffery, Watson, Clifford & Nakayama, 2003; Valentine, 1991). According to this framework, each individual face is represented by a unique multi-dimensional vector from the norm, with the dimensions of face-space representing information that is critical for face identification. Exaggeration of the difference between an individual face and an average face creates a caricature that is easier to recognize than the original face, as would be expected if identity is represented as a deviation from the norm (Rhodes *et al.*, 1987).

Norm-based coding of facial identity has recently been demonstrated in adults using adaptation paradigms: adapting (exposure) to a face for several seconds biases perception of a subsequent face, so that an average face, seen correctly as having no particular identity before adaptation, begins to resemble the computationally opposite identity (Leopold, O'Toole, Vetter & Blanz, 2001). For example, if Dan has a larger-than-average forehead and a smaller-than-average mouth (among other differences from average), adapting to a face computationally opposite to Dan (e.g. a face with a small forehead and a large mouth) causes an average to look more like Dan (see Figure 1).

Neuroimaging studies also support norm-based coding of facial identity. Activation in the fusiform face area (FFA), an area in the fusiform gyrus that responds selectively to face stimuli (Kanwisher, McDermott & Chun, 1997), decreases with multiple presentations of faces that vary along a single identity vector relative to the average face (e.g. faces that have an increasingly broad chin or an increasingly thin nose), but does not decrease with multiple presentations of faces that are equidistant from the mean but fall on different identity vectors (Loffler, Yourganov, Wilkinson & Wilson, 2005). Consistent with these findings, recent electrophysiological findings from nonhuman primates also provide evidence of norm-based coding of faces. Individual face-responsive neurons in the monkey anterior infero-temporal cortex respond to deviations from the average, with systematic increases in firing as faces are moved along identity vectors away from the average face (i.e. with increasing identity strength; Leopold, Bondar & Giese, 2006).

To date, no study has examined the face identity aftereffect in children, even though developmental differences in the use of adaptive face-coding mechanisms could potentially account for children's immature face recognition skills. In the present study, we examined whether 8-year-old children demonstrate adaptive coding of facial identity, consistent with norm-based coding. By age 8, acuity, contrast sensitivity, and many aspects of

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**Figure 1** The centre face represents the average face morphed from 20 adult male faces. Dan and anti-Dan lie on opposite sides of the average face along an identity trajectory (solid line), whereas Jim and anti-Jim lie on a different identity trajectory (dotted line). Faces of varying identity strengths can be created by morphing the average face with Dan's original face (30, 60, and 90% Dan). Adapting to anti-Dan pulls the observer's internal representation of an average face towards anti-Dan, as indicated by the solid grey arrow and faded average face, such that the physically average face stimulus will now look more like Dan to the observer.

higher-order vision are adult-like (Ellemborg, Lewis, Liu & Maurer, 1999; Mayer & Dobson, 1982; Parrish, Giaschi, Boden & Dougherty, 2005), and children perform (nearly) as well as adults on some measures of face processing, such as holistic processing (Carey & Diamond, 1994; de Heering, Houthuys & Rossion, 2007; Mondloch, Pathman, Maurer, Le Grand & de Schonen, 2007; Pellicano & Rhodes, 2003; Tanaka, Kay, Grinnell, Stansfield & Szechter, 1998) and recognizing faces based on changes in feature shape or external contour (e.g. Mondloch, Le Grand & Maurer, 2002). However, they are much worse than adults at recognizing facial identity across changes in point of view or based on the spatial relations of facial features, such as the distance between the two eyes (Mondloch, Geldart, Maurer & Le Grand, 2003; but see also Gilchrist & McKone, 2003, and Pellicano, Rhodes & Peters, 2006). Their immaturity in processing the spatial relations of features is evident even when memory demands are eliminated, as well as when the salience of feature cues is reduced (Mondloch, Dobson, Parson & Maurer, 2004).

Neurological evidence also reveals significant changes in face processing after age 8. Two studies reported no

evidence in 8-year-olds of selective activation in the right anterior fusiform gyrus, or the classic FFA (Aylward, Park, Field, Parsons, Richards, Cramer & Meltzoff, 2005; Gathers, Bhatt, Corbly, Farley & Joseph, 2004), with the earliest face-selective activation in the FFA evident at age 9–11 (Gathers *et al.*, 2004) or 12–14 years (Aylward *et al.*, 2005). Other studies documented changes in the distribution of face-selective areas beyond 12 years of age (Passarotti, Paul & Stiles, 2001; Passarotti, Paul, Bussiere, Buxton, Wong & Stiles, 2003). A more recent study, carefully taking into account age-related differences in BOLD signals that index neural activity, revealed that children aged 7–11 years do demonstrate face-selective right FFA activation, although this face-selective area was significantly smaller than in adults until 12–16 years of age (Golari, Ghahremani, Whitfield-Gabrieli, Reiss, Eberhardt, Gabrieli & Grill-Spector, 2007). Similarly, the responsiveness of the face-selective negative event-related potential (ERP) component N170 (Bentin, Allison, Puce, Perez & McCarthy, 1996) to different types of facial stimuli (e.g. inverted vs. upright faces) changes with age from 8 years to adolescence (Itier & Taylor, 2004). Therefore, given such immaturities in children's face processing, a natural

question arises as to whether 8-year-olds demonstrate facial identity aftereffects, which are indicative of norm-based coding.

In order to test for adaptive face coding in children, it was necessary to modify previous paradigms that have been used with adults (e.g. Leopold *et al.*, 2001; Rhodes & Jeffery, 2006) to be more child-friendly and appropriate for testing 8-year-olds. We developed a cover story involving a team of brothers who look similar to each other and who are competing against another team of brothers. To facilitate children's learning during the training phase, we also chose to require children to learn only two identities; that is, two teams of brothers, whereas adult paradigms have used four identities (e.g. Leopold *et al.*, 2001). We first trained 8-year-olds and adults to recognize two facial identities (Dan and Jim for half the subjects; Dan and Rob for the other half), and then tested their recognition of faces with weaker identity strengths both before and after adaptation. If children, like adults, use adaptive face coding, then adapting to a particular facial identity (e.g. anti-Dan) should bias the child's perception such that the average face (i.e. a neutral identity) begins to resemble a face that is computationally opposite to the adapting face (i.e. Dan; see Figure 1). Adapting to a face on a different identity vector (e.g. anti-Jim) should have no such effect. If children do not use adaptive face coding, being exposed to an adapting face should not shift children's perception of a subsequent face in the direction opposite the adapting face.

## Methods

### Participants

Thirty-two adults (16 male;  $M = 20.3$  years,  $SD = 2.6$  years) and 32 8-year-olds (19 male;  $M = 8.2$  years,  $SD = 0.4$  years) participated in the study. All participants were Caucasian, with normal or corrected-to-normal vision. Children were recruited from names on file of mothers who had volunteered for developmental studies at the time of the child's birth, or through a longitudinal study on the development of cognitive and perceptual skills. Adults were recruited from a first year psychology course and received course credit for their participation. One additional child did not pass the training criterion (described below) and therefore was excluded from the study.

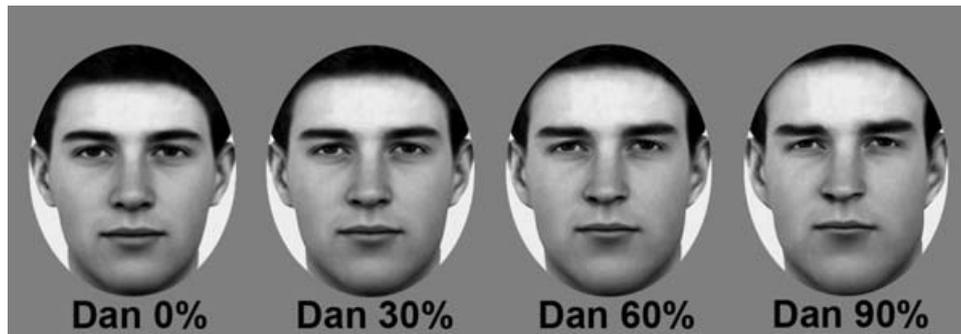
Participants were divided into two groups based on the face pair they were discriminating: Dan vs. Jim or Dan vs. Rob.

### Stimuli

The average face was created by morphing 20 adult male faces using Gryphon Morph. The training and test stimuli were taken from identity trajectories that pass through the average face, with an original face and an anti-face on opposing sides. There were three original adult male faces (Dan, Jim, and Rob; Figure 2). Anti-faces were



**Figure 2** Top row: Team captains are shown at 100% identity strength. Observers were trained to identify two faces (half were trained to discriminate Dan vs. Jim; half were trained to discriminate Dan vs. Rob). Bottom row: Anti-faces were created by caricaturing the structure of the average face away from the original faces (team captains) by 80% using Gryphon Morph.



**Figure 3** An example of the four identity strengths (Dan) used in the baseline phase, and as the target faces in the adaptation phase. 0% identity represents the average face created from a pool of 20 male faces. 30, 60, and 90% identity strengths were created by morphing the original face (team captains) with the average face.

created by caricaturing the structure of the average face away from the original faces by 80% (Rhodes & Jeffery, 2006; Figure 2). The training and test stimuli were created by morphing each original face towards the average face, in order to create faces with weaker identity strengths of the original faces (Figure 3). All faces had the texture of the average face. The size of the oval window through which the faces could be seen was 7.6 cm × 9.5 cm (viewing angle of 4.35° × 5.44° from a viewing distance of 100 cm).

#### Procedure

The task and the purpose of the study were explained briefly to the children, their parents, and the adult participants. The children gave verbal assent along with their parents' written consent for participation, and the adult participants gave written consent. The task required approximately 30–45 minutes to complete. Each participant was tested individually in a small room with dim lighting at a university. This study was approved by the research ethics boards of McMaster University and the University of Western Australia.

Children and adults first completed a training block of 20 trials in which they were introduced to two faces, referred to as 'team captains', Dan and Jim (Group 1) or Dan and Rob (Group 2).<sup>1</sup> Only faces of 100% identity strength were shown. For the first 10 trials, the faces remained on the screen until a response was made; for the last 10 trials, each face was shown for 400 ms. Auditory feedback on accuracy was given on each trial. Each participant was required to correctly identify all of the faces shown on the last five trials in order to proceed to the next training phase. If necessary, the training block was repeated once (seven children, two adults).

Children and adults were then introduced to the 40% and 60% identity strength faces as 'brothers of the team

captains that are on their team'. During this training phase, identity strengths of 40%, 60%, and 100% of each target face were shown twice per block, and participants were asked to indicate whether the face that appeared on the screen was on Dan's team or Jim/Rob's team. The purpose of this second training phase was to ensure that 8-year-olds could identify faces with weaker identity strengths as resembling the correct target face. For the first block of 12 trials, each face remained on the screen until a response was made; for all subsequent blocks of 12 trials, each face was shown for 400 ms. Blocks were repeated until the participant correctly identified four of the last five 40% and 60% identity strength faces. Auditory feedback was given on each trial. Only one child could not reach this criterion after 30 minutes of training, and his data were excluded from the analysis.

During the baseline phase, participants saw four identity strengths of each face (0%, 30%, 60%, and 90% Dan and Jim/Rob; see Figure 3) eight times for a total of 64 trials, divided into three blocks. The order of presentation within each block was randomized, and each face appeared on the screen for 400 ms. Observers were asked to respond whether the face belonged to a person on Dan's team or Jim/Rob's team. No feedback was given. Following Leopold *et al.* (2001), half of the trials of 0% identity strength (i.e. the average face) were assigned to each identity (Dan or Jim/Rob) and scored 'correct' if the response matched that identity.

During the adaptation phase, children and adults were required to watch the adapting face (anti-Dan or anti-Jim/Rob; Figure 2) for 5 seconds before the target face appeared for 400 ms. In order to ensure that 8-year-olds would attend fully to the adapting face and also enjoy the task, we modified previous paradigms (e.g. Leopold *et al.*, 2001; Rhodes & Jeffery, 2006) into a game in which participants were the judges responsible for assigning points to two competing teams. We explained that the adapting faces were 'robbers trying to steal something', and that two teams of brothers would work hard to catch these robbers. Participants were warned to keep watching the robber's face carefully because as soon as

<sup>1</sup> Statistical analyses with *group* (Dan/Jim or Dan/Rob) as an additional between-subjects variable revealed no significant interactions with *age* (8-year-olds vs. adults), and therefore data were collapsed across this variable.

the robber disappeared, they would see who caught the robber (target face) for only a short time, and we would not want to mistakenly assign a point to the wrong team. Points were assigned to the teams based on the participant pressing one of two keys, depending on whether the person who caught the robber was on Dan's team or Jim/Rob's team. The instructions were identical for children and adults.

On matched trials, the anti-face and the target face were from the same identity trajectory (e.g. anti-Dan followed by 0, 30, 60, or 90% Dan). On mismatched trials, the anti-face and the target face were from different identity trajectories (e.g. anti-Dan followed by 0, 30, 60, or 90% Jim/Rob). There were six matched trials and six mismatched trials per target face (96 trials total). Some 'escape' trials were included in which no target face appeared because 'the robber had escaped', so as to allow children to take a short break and choose a sticker to take home. Adults were also given the option of taking a short break. Participants were not required to provide any response on these escape trials (12 total). The 108 trials were divided into six blocks of 18 trials (eight matched trials, eight mismatched trials, and two escape trials per block).<sup>2</sup> No feedback was given other than words of encouragement.

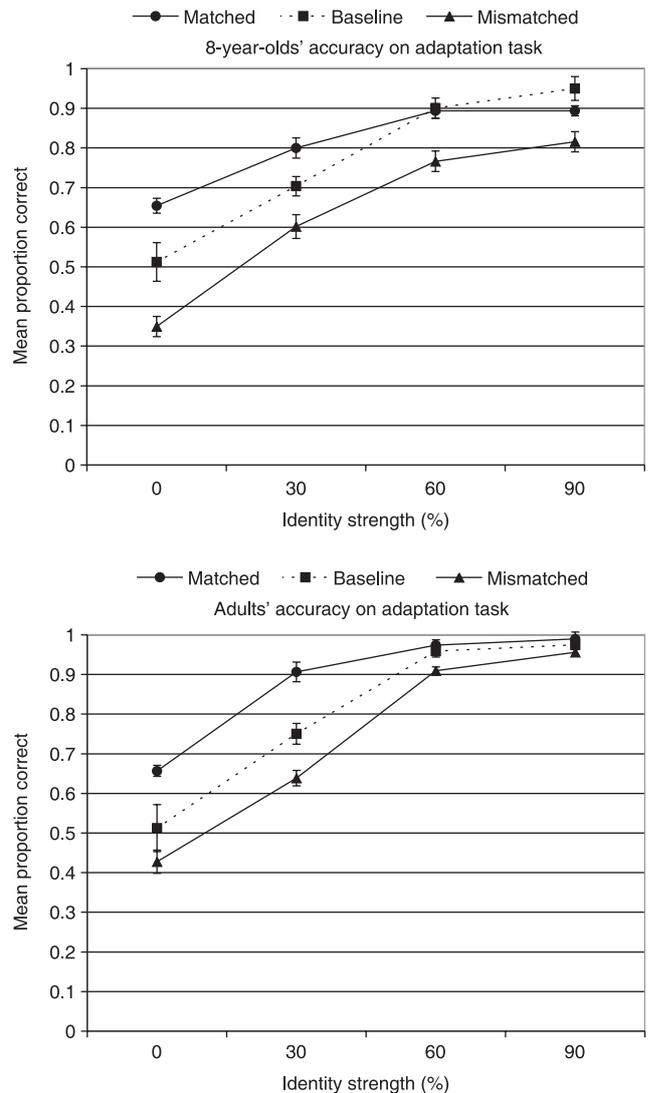
## Results

Both 8-year-olds and adults showed the pattern of responses predicted by norm-based coding. Adapting to a face shifted the perception of target faces on the same identity trajectory (matched trials) towards the opposite face (Figure 4); that is, after adapting to anti-Dan, all identity strengths of Dan looked more like Dan, and the previously neutral 0% (average) face took on the identity of Dan. These effects were not observed on mismatched trials where the adapting and test faces were not opposite. Importantly, the size of the shifts was similar for the two age groups, indicating mature norm-based coding in 8-year-olds.

This pattern of results was confirmed with a mixed  $3 \times 2 \times 2$  ANOVA with *condition* (matched adaptation, mismatched adaptation, or baseline trials) and *identity strength* (0% or 30%)<sup>3</sup> as within-subjects variables, and *age* (8-year-olds vs. adults) as the between-subjects variable. There was a significant main effect of *condition*,  $F(2, 124) = 62.88$ ,  $p < .001$ , indicating that performance differed across the three types of trials. Critically, however, the *condition*  $\times$  *age* interaction was not significant,  $F(2, 124) = .36$ ,  $p = .70$ , indicating that the differences between

<sup>2</sup> Due to a coding error, there was half the number of mismatched adaptation trials at the 0% identity strength than at the other identity strengths.

<sup>3</sup> The analysis was restricted to identity strengths 0% and 30% because baseline accuracy was high at identity strengths 60% and 90%, masking any aftereffect (see Figure 4).



**Figure 4** Accuracy on baseline and adaptation trials for (a) 8-year-olds and (b) adults (mean  $\pm$  one standard error). On matched adaptation trials, observers adapted to the anti-face opposite the target face. On mismatched adaptation trials, observers adapted to a non-opposite anti-face before viewing the target face (e.g. anti-Jim followed by 30% Dan).

conditions did not vary with age. There were no other interactions with the variable *condition* (*condition*  $\times$  *identity strength*,  $F(2, 124) = .31$ ,  $p = .74$ , and *condition*  $\times$  *identity strength*  $\times$  *age*,  $F(2, 124) = 1.43$ ,  $p = .24$ ). There was also a main effect of *age*,  $F(1, 62) = 5.39$ ,  $p = .02$ , indicating overall better performance by adults than 8-year-olds.

Because norm-based coding predicts different shifts in the perception of facial identity after adapting to matched (opposite) and mismatched (non-opposite) anti-faces, the main effect of *condition* was further analyzed by comparing the means for baseline to those for matched trials and to those for mismatched trials, with a Bonferroni correction for multiple comparisons. As predicted by norm-based coding, mean accuracy on matched trials

(75.4%,  $SE = 1.4\%$ ) was significantly higher than on baseline trials (61.9%,  $SE = 1.2\%$ ),  $p < .001$ . In contrast, accuracy was lower on mismatched trials ( $M = 50.4\%$ ,  $SE = 2.1\%$ ) than on baseline trials ( $M = 61.9\%$ ,  $SE = 1.2\%$ ),  $p < .001$ .<sup>4</sup>

The ANOVA also revealed a main effect of *identity strength*,  $F(1, 62) = 157.54$ ,  $p < .001$ , indicating better performance at 30% identity strength than 0% identity strength, as expected because faces at higher identity strengths should be easier to identify (stronger identity strengths are created by morphing the face towards the original identity and away from average), and because baseline performance at 0% identity strength should be at chance. The *identity strength*  $\times$  *age* interaction was non-significant,  $F(1, 62) = 1.16$ ,  $p = .29$ .

Because adaptation trials differed from baseline trials in that observers adapted to a face before responding to the target face, we also directly compared performance between matched and mismatched adaptation trials. There was a significant main effect of *condition*,  $F(1, 62) = 96.08$ ,  $p < .01$ , and a main effect of *age*,  $F(1, 62) = 4.86$ ,  $p = .03$ , but no *condition*  $\times$  *age* interaction,  $F(1, 62) = 0.00$ ,  $p = .96$ , indicating that the size of the identity aftereffect was similar for both 8-year-olds and adults.

## Discussion

These results demonstrate that in a child-friendly two-alternative forced-choice paradigm, 8-year-olds and adults show the same facial identity aftereffect. This is the first demonstration of a face aftereffect in children, and it suggests that the mental representation of faces is organized similarly in 8-year-olds and adults.

The results are consistent with the hypothesis that, for both 8-year-olds and adults, faces are coded in a multi-dimensional face-space centered on an average face (Valentine, 1991). The anti-faces in the current study were computationally derived to differ maximally from the original faces along a vector passing through the origin (i.e. the average face). The results are as would be expected if adapting to these anti-faces (matched trials) shifted the mental representation of the average face towards the adapting face, such that perception of subsequent faces was biased toward the original identity. Adapting to a face on another vector (mismatched trials) did not bias perception towards the original identity. The results suggest that, like adults, 8-year-old children represent individual faces along vectors in a multi-dimensional face-space passing through the norm. Norm-based coding of facial identity is supported by evidence that faces further away from average generate a stronger neural

response in face-selective areas of the human brain (Loffler *et al.*, 2005) and the monkey brain (Leopold *et al.*, 2006). The special role of the average face in encoding facial identity may be established early in development, as evidenced by the fact that beginning just a few months after birth, both human and monkey infants respond to an average face as if it is familiar (de Haan, Johnson, Maurer & Perrett, 2001; Kelly, Quinn, Slater, Lee, Gibson, Smith, Ge & Pascalis, 2005; Myowa-Yamakoshi, Yamaguchi, Tomonaga, Tanaka & Matsuzawa, 2005).

The facial identity aftereffect is selective for pairs of opposite faces, such as Dan and anti-Dan (Leopold *et al.*, 2001; Rhodes & Jeffery, 2006; this study), suggesting that the neural mechanisms underlying face processing utilize opponent-based coding, accomplished by pairs of neural populations that are adaptively tuned to above-average and below-average values for each dimension of face-space. The relative activation of the two neural populations signals the value for each face on that dimension, and equal activation signals the average value (Rhodes & Jeffery, 2006; Rhodes, Robbins, Jaquet, McKone, Jeffery & Clifford, 2005). For example, since Dan has a larger-than-average forehead (see Figure 1), seeing Dan's face will more strongly activate the neural populations encoding larger-than-average forehead size (relative to those responsive to smaller foreheads), thereby temporarily suppressing the activity of those neurons. This temporary suppression is manifested as a bias in the perception of a subsequently viewed face towards having a smaller-than-average forehead. Similar mechanisms will occur simultaneously for all dimensions of face-space, thereby shifting the position of average in face-space temporarily, leading to an identity aftereffect.

In adults, this process has been shown to be dynamic with the strength of the facial identity aftereffect increasing logarithmically with increasing adaptation duration, and decaying exponentially with time following adaptation (Leopold, Rhodes, Muller & Jeffery, 2005; Rhodes, Jeffery, Clifford & Leopold, 2007a). Therefore, brief adaptation, as in the current paradigm, only temporarily shifts the representation of the average face. However, the same adaptive coding mechanism may be involved in real-world face processing that dynamically calibrates neuronal responses to the range of faces most commonly experienced (Rhodes, Maloney, Turner & Ewing, 2007b). By continuously updating the central tendency of faces experienced, and by encoding each face in terms of deviations from the average, neural efficiency is maximized because the most commonly experienced faces activate the least response (Leopold *et al.*, 2001, 2006; Rhodes & Jeffery, 2006). The present findings suggest that such an adaptive coding mechanism for facial identity is functional by 8 years of age.

The neural locus of the face identity aftereffect appears to be in high-level visual areas, as suggested by its robustness to changes in size, position, and angle of the adapting and test stimuli (Leopold *et al.*, 2001; Rhodes

<sup>4</sup> On mismatched trials (e.g. adapting to anti-Jim and then identifying Dan), the perception of facial identity shifts along a trajectory different from that of the target face (Dan) and hence the target face is *less* likely to be correctly identified (e.g. all faces look less like Dan because they look more like Jim).

*et al.*, 2003; Watson & Clifford, 2003; Zhao & Chubb, 2001), as well as the time-course of the aftereffects (Rhodes *et al.*, 2007a). In adults, fMRI activation reveals neural adaptation in the FFA that parallels face identity aftereffects: repeated presentation of faces on a single identity vector relative to average leads to adaptation of the BOLD signal, unlike repeated presentation of faces on different identity vectors (Loffler *et al.*, 2005). In the current study, we found adult-like identity aftereffects at age 8 years, the age at which previous fMRI studies indicate that the fusiform face area is not yet more responsive to faces than objects (Aylward *et al.*, 2005; Gathers *et al.*, 2004), or at least not at adult levels (Golari *et al.*, 2007; Scherf, Berhmann, Humphreys & Luna, 2007). Together, the results suggest that children can develop adaptive coding of faces independent of a large face-selective FFA.

Despite the presence of adult-like adaptive face-coding processes indicative of norm-based coding in 8-year-olds, face processing continues to improve after 8 years of age. Indeed, in the current study, adults were more accurate overall in identifying faces than 8-year-olds. Previous studies have shown that 8-year-olds perform poorly when recognizing facial identity across changes in point of view or based on the spatial relations of facial features (Mondloch *et al.*, 2002, 2003). Accordingly, children may not show adult-like aftereffects when there are manipulations in point of view (Anderson & Wilson, 2005; Jeffery, Rhodes & Busey, 2006; Jiang, Blanz & O'Toole, 2006, 2007) or the spatial relations of facial features (Robbins, McKone & Edwards, 2007; Watson & Clifford, 2003; Webster & MacLin, 1999). Future studies should therefore examine the nature of the changes in face-space that occur with development. Perhaps with increased expertise, children become better at adjusting the weights given to each dimension within face-space to reflect the utility of that dimension as a cue to identity. Alternatively, children may develop additional dimensions, and/or become better at making finer discriminations within the dimensions (Burton, Jenkins, Hancock & White, 2005). An additional possibility is that the norm for children is less stable and shifts more easily and permanently by exposure to new faces, as suggested by the reversal of the other-race bias in Korean adults adopted into European families before age 9, such that they were better at identifying Caucasian faces than Asian faces, much like the Caucasian control group (Sangrigoli, Pallier, Argenti, Ventureyra & de Schonen, 2006). This hypothesis could be tested directly by comparing the timecourse of the identity aftereffect for children and adults using the technique developed for this study.

In summary, this is the first study to demonstrate adaptive coding of facial identity in children, consistent with children's use of norm-based coding of facial identity. Like adults, 8-year-olds' perception of identity shifts towards the opposite identity after viewing a face. These results suggest that adaptive coding of identity is developed by 8 years of age. The technique developed here is suitable

for exploring the mental representation of faces in special populations with deficits in face processing such as children with autism and adults with prosopagnosia.

## Acknowledgements

This research was funded by a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) to DM, a graduate scholarship from NSERC to MN, and a grant from the Australian Research Council to GR.

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Received: 7 May 2007

Accepted: 19 August 2007