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Effect of adaptor duration on 8-year-olds' facial identity aftereffects suggests adult-like plasticity of the face norm

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ABSTRACT

Adapting to a face shifts the perceived identity of a subsequent face in the direction opposite to the adapting face, a phenomenon known as a face identity aftereffect. In the present study, we examined the temporal dynamics of such aftereffects in children at an age when face processing abilities are not yet adult-like. We hypothesized that children's difficulties in face processing may stem from an unstable mental representation of facial identity, which may be especially prone to adaptation aftereffects. Using a novel procedure designed especially for children, we show that both 8-year-olds and adults demonstrate identity aftereffects of similarly small size after just one second of viewing the adapting face, and that the strength of the aftereffect increases logarithmically and similarly with longer adapting durations for both age groups. The findings suggest that the mental representation of facial identity in 8-year-olds is no more malleable than that of adults, at least in response to short-term adaptation.

1. Introduction

Adults have a remarkable ability to recognize the identity of faces, even years after the last encounter (e.g., Bahrick, Bahrick, & Wittlinger, 1975). This success undoubtedly arises from the efficiency with which the visual system encodes facial identity. One useful framework for describing adults' coding of facial identity is face-space, a multi-dimensional space in which individual faces are coded by vectors describing their deviation from the norm or average of previously encountered faces (Valentine, 1991). Evidence supporting norm-based coding comes from a variety of sources, including studies showing that easily recognized caricatures can be created by exaggerating the deviations of an individual face away from the average (e.g., Rhodes, Brennan, & Carey, 1987). Additional evidence for norm-based coding of faces has been provided through adaptation paradigms. In a typical adaptation paradigm, an observer adapts to a face with a particular distortion, which biases his/her perception of subsequent faces in the opposite direction relative to the norm (e.g., Webster & MacLin, 1999). For example, an observer will perceive an undistorted face to be "more expanded than normal" after adapting to a contracted face – a phenomenon known as a figural distortion aftereffect (e.g., Rhodes et al., 2004; Watson & Clifford, 2003; Webster & MacLin, 1999), or the eye height will appear "too high" in an undistorted face after adapting to a face with very low eyes (e.g., Robbins, McKone, & Edwards, 2007; Susilo, McKone, & Edwards, 2010). Adaptation aftereffects can also be induced for particular identities, a phenomenon called an identity aftereffect. In this case, an anti-face (e.g., anti-Dan) is created to be the opposite of an original identity (e.g., Dan) structurally, relative to the average face (e.g., if Dan has a larger-than-average forehead, anti-Dan has a proportionately smaller-than-average forehead). Adapting to anti-Dan shifts the perceived identity of a subsequent face in the opposite direction, making the face appear more Dan-like (e.g., Leopold, O'Toole, Vetter, & Blantz, 2001; Loffler, Yourganov, Wilkinson, & Wilson, 2005; Rhodes & Jeffery, 2006). Importantly, adapting to the average face does not shift the perception of non-average faces (Leopold et al., 2001; Webster & MacLin, 1999), and much smaller shifts in perceived identity are observed with pairs of faces that are not opposite each other relative to the average (Anderson & Wilson, 2005; Rhodes & Jeffery, 2006), findings that suggest that representations of facial identity are organized around the average face. Moreover, adapting to a face farther from the average face induces a larger aftereffect (Jeffery et al., 2010; Robbins et al., 2007; Susilo et al., 2010), a pattern predicted by a norm-based model in which the average is constantly updated but which has been interpreted as inconsistent with exemplar-based models (e.g., Jeffery et al., 2010; Susilo et al., 2010).

The face identity aftereffect appears to involve high-level visual mechanisms, as face aftereffects survive changes in retinal position (e.g., Leopold et al., 2001), size (e.g., Anderson & Wilson, 2005; Zhao & Chubb, 2001), and viewpoint (e.g., Jiang, Blanz, & O'Toole, 2006) between the adapting and test faces. Like low-level visual aftereffects, identity aftereffects increase logarithmically with

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longer adaptation durations and decrease exponentially with longer presentations of the test face before a response can be made (e.g., Leopold, Rhodes, Muller, & Jeffery, 2005; Rhodes, Jeffery, Clifford, & Leopold, 2007). However, with famous faces and longer adaptation durations, face aftereffects can last 1–7 days after adaptation (Carbon & Ditye, 2010; Carbon et al., 2007), although the effects become weaker with increasing delay. Face adaptation, like other low-level adaptation mechanisms, appears to have a functional role in optimizing face processing – it reduces the response common to all faces (i.e., coding of average face), effectively freeing up neural resources to code only the distinguishing properties that allow easy and fast individual face recognition. Supporting evidence comes from a recent study by Rhodes and colleagues (2010) which showed that adapting to an averaged face of a particular race (i.e., Caucasian or Asian) for 5 min enhanced recognition of individual identities from that race but not the unadapted race.

It takes many years for children to reach adult-like levels of performance on many face recognition tasks. Even at age 14, children make more errors than adults in recognizing faces that differ only in the spacing of individual features (Baudouin, Gallay, Durand, & Robichon, 2010; Mondloch, Le Grand, & Maurer, 2002; but see McKone & Boyer, 2006). Moreover, in children 5–11 years old, the area of face-selective activation in the right fusiform gyrus does not appear consistently in the same spatial region as in adults, nor is its location consistent from child to child (Golarai et al., 2007; Scherf, Berhmann, Humphreys, & Luna, 2007; but see also Cantlon, Pinel, Dehaene, & Pelphrey, 2010 for recent evidence of adult-like face-selectivity in 4-year-olds). The effective connectivity among face-responsive regions (i.e., the core face network) that is seen in adults appears to be established some time after 11 years of age (Cohen Kadosh, Cohen Kadosh, Dick, & Johnson, 2010), and face-selective activation in right fusiform gyrus is still not as large as in adults at 12–16 years of age (Golarai, Liberman, Yoon, & Grill-Spector, 2009; Golarai et al., 2007; Scherf et al., 2007). Yet by age 6, children, like adults, recognize a familiar face more quickly if they see its caricature (Chang, Levine, & Benson, 2002) and demonstrate figural distortion aftereffects (Jeffery et al., 2010; Short, Hatry, & Mondloch, 2011; see Anzures, Mondloch, & Lackner, 2009, for similar evidence in 8-year-olds), with larger aftereffects for larger distortions (Jeffery et al., 2010), consistent with norm-based coding. By age 8, children demonstrate identity aftereffects of similar magnitude to those of adults (Nishimura, Jeffery, Pellicano, & Rhodes, 2008), even when the adaptor and test faces have a different size to rule out explanations based solely on low-level adaptation (Pimperton, Pellicano, Jeffery, & Rhodes, 2009). These findings suggest that by at least ages 6–8 years, children, like adults, code facial identity relative to average, and hence that their immaturities in face processing do not arise from an absence of norm-based coding.

One potential source for their behavioral immaturities when processing faces, if not in norm-based coding per se, is that the norm in children's face-space is less stable and more easily affected by exposure to new faces. Indeed, Hills and colleagues (2010) found evidence of greater plasticity when they examined adaptation aftereffects in faces with distorted eye positions. Children (age 6–12 years) showed larger aftereffects than adolescents (age 13–18 years). Moreover, whereas adolescents, like adults (Robbins et al., 2007), evinced large aftereffects for symmetric distortions (both eyes up or down) but not asymmetric distortions (one eye up and one eye down), a pattern consistent with the dimensions likely to be useful in distinguishing facial identity, children showed similar aftereffects for the two types of distortion (Hills et al., 2010). The findings suggest that children's face-space is more malleable and easily adapted. One contradictory finding is that adults demonstrate a larger figural distortion aftereffect than children aged 4–6 years after adapting to a contracted face (Jeffery et al., 2010): both groups saw subsequent faces as more expanded, but the effect was larger in adults. However, as noted by the authors of the study, this result could indicate that children perceived the contracted face as less distorted than did adults, and not necessarily that children's face-space is less malleable than that of adults. Supporting evidence for this interpretation comes from the fact that children were consistently worse than adults in perceiving subtle distortions pre-adaptation, as would be expected if children's face-space is more broadly tuned (Jeffery et al., 2010).

Greater plasticity in children's mental representation of facial identity is suggested by a study that examined the effect of childhood experience on the other-race effect: better recognition of faces from one's own race/ethnic group than faces of other races (Brigham, Maass, Snyder, & Spaulding, 1982; Meissner & Brigham, 2001; Platz & Hosch, 1988). Interestingly, Korean adults who had been adopted into Caucasian European families before 9 years of age showed a reversal of the other-race effect, recognizing Caucasian faces better than Asian faces, much like Caucasian adults (Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005). In contrast, exposure to faces of an unfamiliar race beginning in adulthood has a minimal effect (reviewed in Meissner and Brigham (2001)). The contrasting findings suggest that before 9 years of age, children's norm can be more easily (and perhaps permanently) changed. Converging evidence comes from the other-age effect: 3-year-olds, like adults, are better at discriminating among adult faces (to which they are exposed everyday) than among newborn faces, which they rarely see (Cassia, Kuefner, Picozzi, & Vescovo, 2009). However, exposure to infant faces reverses the other-age effect in 3-year-olds but not adults: 3-year-olds with a younger sibling, unlike first time mothers of 9-month-old infants, are equally good at discriminating adult and infant faces.

In the current study, we examined the malleability of the face norm more directly by examining the effect of adaptor duration on the identity aftereffect in adults and 8-year-old children, an age at which performance on face identity tasks is still not adult-like. If children's face norm is more plastic, children's identity aftereffects could emerge more quickly than adults' aftereffects. Although previous work shows that their identity aftereffects are of similar size to those of adults after 5 s of adaptation (Nishimura et al., 2008; Pimperton et al., 2009), their aftereffects might be manifest more quickly and hence be larger after just 1 or 2 s of adaptation. Alternatively, the timing of the emergence of the aftereffect may be similar but with adaptation durations longer than 5 s, the aftereffect may grow stronger than in adults.

We created a novel child-friendly adaptation paradigm, modeled on previous paradigms examining the temporal dynamics of identity aftereffects in adults (e.g., Leopold et al., 2005; Rhodes, Jeffery et al., 2007). In the previous studies, adults were trained for several days to correctly identify four faces, as well as their weaker identity strengths (i.e., incremental morphs between the original face and an average face). The adaptation phase began only after adults could identify faces correctly at 15% identity strength. On each trial, an adapting face (the opposite of one of the original faces relative to an average face, e.g., anti-Dan) was shown for one of 5 durations (1, 2, 4, 8 and 16 s), followed by the test face, which was always the average face and which had not been seen during training. The perceived identity of the test face was measured by asking adults to rate their impression of a cued identity (e.g., "Dan") on a 7-point scale, ranging from 1 = No Identity to 7 = Full Identity, with larger values indicating that the average face was perceived more strongly as taking on the identity opposite the adapting face. The size of the aftereffect increased logarithmically with longer adaptation durations.

We combined elements of the adult paradigm described above with a child-friendly paradigm used previously (Nishimura et al., 2008) to create a novel paradigm suitable for probing the temporal dynamics of identity aftereffects in children. First, we trained children and adults to recognize two identities, Dan and Jim, as well as their weaker identity strengths at 30% and 60%, which were referred to as the brothers of Dan and Jim, "who look like Dan/Jim". After training, we took baseline measurements of perceived identity of faces at varying identity strengths (0%, 20%, 40%, 60%, 80%) without adaptation. Instead of having children rate "the impression" of an identity, as was done in previous adult studies but may be difficult for children, we used a 5-alternative forced-choice task in which observers decided whether the test face was Dan, one of Dan's brothers, Jim, one of Jim's brothers, or none of the above. We then adapted participants to morphed opposites of Dan and Jim for varying adaptation durations (1, 2, 4 and 8 s) and measured the perceived identity of the 0% (average) face. Adaptation should shift responses from "none" toward the identity opposite the adapting face (e.g., toward Dan after adaptation to anti-Dan and toward Jim after adaptation to anti-Jim). If children's norm is more malleable, children's choices should shift (in the expected direction) more than those of adults.

2. Methods

2.1. Participants

Final data analyses were based on 24 adults and 24 8-year-olds (±3 months) with normal or corrected-to-normal vision. An additional 15 8-year-olds were recruited for the study but did not participate because they failed a screening test for normal vision, which occurs frequently at this age because the child has not yet had an eye exam and parents are unaware of any problem. Specifically, they failed to read the 20/20 line on a letter chart and/or to demonstrate clinically normal stereoacuity on the Titmus test. Data from two additional 8-year-olds were not recorded because of computer error. An additional seven 8-year-olds (21% of the sample of 8-year-olds tested) participated in the study but were excluded from the analysis because they did not pass the adaptation criterion (see below, $n = 4$) or they could not follow the instructions ($n = 3$).

2.2. Stimuli

The face stimuli were the same as those used in previous studies of the identity aftereffect and have been described in detail previously (Rhodes & Jeffery, 2006; Nishimura et al., 2008). Briefly, an average face was created from 20 grayscale images of male faces based on vector averaging of the position of 165 landmarks on each face. From those 20 faces, two identities were chosen (Dan and Jim) as the faces to be learned. Weaker identity strengths of Dan and Jim (0%, 20%, 30%, 40%, 60%, 80%, 90%) were created by morphing together the average face with the original faces. Opposite identities (anti-Dan and anti-Jim) were created by calculating the structural deviations between the original face and the average face (e.g. Dan has a bigger-than-average forehead) and re-creating them in the opposite direction (e.g. anti-Dan has a smaller-than-average forehead) at 80% of the original values. Test and adapting faces were 7.6 cm × 7.8 cm on the screen (4.35° × 4.45° of visual angle when viewed from 100 cm).

Eighty photographs of crowds of people and 80 photographs of objects and animals were chosen from the Internet, to be shown after each adaptation trial in order to allow any aftereffects to dissipate before the next adaptation trial. Images of crowds were typically group shots and contained from 3 to 50 people; they were shown centrally and were large enough to take up most of the screen, typically at least 10° × 10° of visual angle. Images of objects and animals were items sufficiently common that they would be familiar to a typical 8-year-old (e.g., scissors, phone, etc.) that were of sufficient quality to allow easy recognition. Images of objects and animals were smaller than the images of the crowds and shown in the periphery. They ranged in size from 68 × 114 pixels (1.2° × 2.0°, an ipod) to 310 × 150 pixels (5.4° × 2.6°, a car).

2.3. Procedure

The paradigm was similar to those used previously (e.g., Leopold et al., 2005; Nishimura et al., 2008; Rhodes, Jeffery et al., 2007), with modifications to be engaging and suitable for children. All responses by the 8-year-olds and adults were given orally, and entered into the computer by the experimenter.

2.3.1. Training 1 – Learning 100% identity strengths

Observers were first trained to learn two identities, Dan and Jim, at 100% identity strength (see Fig. 1). Observers initially saw the faces of Dan and Jim and their names on the screen while the task was explained. On each subsequent trial, a single face appeared on the screen and the observer's task was to respond verbally whether the face was Dan or Jim. Auditory feedback indicated whether the response was correct or incorrect. For the first 10 trials, faces appeared on the screen until a response was made. For subsequent blocks (10 trials/block), faces appeared for 400 ms, and these blocks were repeated until the observer answered all 10 trials correctly within a block. All adults and 8-year-olds met this criterion on their first attempt.

2.3.2. Training 2 – Learning 30% and 60% identity strengths

Observers were introduced to the "brothers" of Dan and Jim (30% and 60% identity strengths), and instructed to answer orally "Team Dan" if Dan (100% identity strength) or one of his brothers was shown, and to answer "Team Jim" if Jim (100% identity strength) or one of his brothers was shown. They received auditory feedback about whether the response was correct or incorrect after each trial. The instructions were given within the context of a story involving the placement of Teams Dan and Jim on their respective school buses, airplanes, or boats to head to a party (see Fig. 2). After each response, a picture of the team was shown to remind observers of the faces belonging to each team. Twelve easy trials (2 trials per face) with unlimited duration were followed by 52 trials with 400 ms presentation times (6 trials per 100% Dan/Jim identity strengths; 10 trials per 30% and 60% Dan/Jim identity strengths).

2.3.3. Training criterion – Assessment of learning

Whether the observers had learned the weaker identities was tested with a block of five trials, each trial showing a face (400 ms) chosen randomly from 30 and 60% Dan and Jim. Each observer was required to respond whether the face belonged to

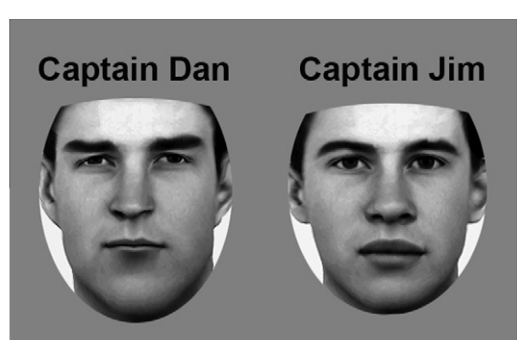

Fig. 1. Team captains, Dan 100% and Jim 100%.

Fig. 2. An example stimulus from Training 2, showing Team Dan (Dan 30%, 60%, 100%) "riding the bus".

"Team Dan" or "Team Jim" correctly on 4/5 trials before proceeding to the baseline phase. No feedback was given during this criterion block. All adults and 22 of the 24 8-year-olds passed this criterion on their first attempt. Two 8-year-olds failed on their first attempt, and completed 10 practice trials, structured as in Training 2, before attempting another criterion block. Both children passed this criterion on their second attempt.

2.3.4. Baseline – Recognition without adaptation

In the baseline phase, each face (0%, 20%, 40%, 60%, 80% Dan or Jim) appeared individually six times for 400 ms for a total of 60 trials. Observers identified the face so that "each person goes to the right party, one for Team Dan and one for Team Jim" using 5 response options: Dan, Jim, one of Dan's brothers, one of Jim's brothers, or an unknown face (explained as a cheater trying to enter the parties uninvited). The option of "cheater" was included because the average face (0%) and weaker identity strengths may appear like neither Dan nor Jim (nor their brothers). No feedback was given other than general words of encouragement.

2.3.5. Adaptation

In the adaptation phase, each trial began with an adapting face (anti-Dan or anti-Jim) shown for 1, 2, 4 or 8 s, followed by a 400 ms presentation of the average face (0% identity strength). The cover story was that the adapting faces were "robbers" stealing something, and the task was to identify who (the test face) caught the robber. Observers identified the test face in the response interval (1000 ms) using the same five response options as in the Baseline phase. After the observer's response was entered, a photograph of one of the 80 pictures of crowds appeared in the center of the screen for 4000 ms, with one of the 80 pictures of objects or animals in the periphery, to allow any aftereffect to dissipate before starting the next trial. Each picture appeared only once during the experiment. We explained that the object in the photograph represented what the "robber" was trying to steal, and the unfamiliar people were in the crowd cheering on Teams Dan or Jim. Children appeared to understand and enjoy the game.

Each adapting face (anti-Dan and anti-Jim) was tested at each adaptor duration eight times (64 trials). Because we were interested in perceived identity following adaptation, the test face was always the average face, for which there is no correct answer. Reminder screens were shown every 20 trials to refresh the observers' memory of the faces of Teams Dan and Jim, which also signaled a scheduled break. An additional 8 trials with no test face were included, in which the screen said "the robber escaped!", to provide an additional opportunity for observers to take a break. No feedback was given except general words of encouragement.

To assess whether children and adults remembered the faces of Dan and Jim throughout the adaptation phase, an additional 8 criterion trials were included in which the test face was 90% Dan or Jim. Observers were required to answer 6/8 criterion trials correctly to be included in the final analysis because we cannot meaningfully assess the aftereffect if the observers have forgotten the original identities. Four children (not included in the final sample) failed to pass this criterion by answering correctly on only 5/8 trials (see Section 2.1), and their data were not included in the data analyses. No adult failed this criterion.

2.4. Preliminary data analysis

The responses from the five response options used in the baseline and adaptation phases were coded to quantify perceived identity, with -2 = Dan, -1 = one of Dan's brothers, 0 = cheater (no identity), 1 = one of Jim's brothers, and 2 = Jim.

For the adaptation results, we calculated perceived identity scores at each adapting duration as the change in the expected direction relative to baseline performance at identity strength 0% (the average face), averaged across anti-Dan and anti-Jim trials. Positive change scores represent shifts in the expected direction (i.e., higher than baseline scores after adaptation to anti-Jim and lower than baseline scores after adaptation to anti-Dan); negative change scores represent shifts in the opposite direction.

3. Results

3.1. Baseline

For the baseline phase, we plotted perceived identity as a function of identity strength of the test face (Fig. 3). A repeated-measures ANOVA on the raw identity ratings revealed that there was a difference in baseline performance between adults and children, with a significant main effect of age, $F(1, 46) = 8.75$, $p < 0.01$, partial $\eta^2 = 0.16$, and a significant age x face interaction, $F(8, 368) = 4.54$, $p < 0.001$, partial $\eta^2 = 0.09$. To further analyze these age effects, we compared performance between adults and 8-year-olds separately for the average face, Dan faces, and Jim faces.

There was no difference in the perceived identity ratings between adults and 8-year-olds on average face (0% identity strength) trials, the point where aftereffects were measured. Both adults ($M = 0.49$, SEM = 0.09) and 8-year-olds ($M = 0.29$, SEM = 0.09) showed a similar bias to rate the average face more as Jim (i.e. positive ratings) than Dan, but critically, there was no

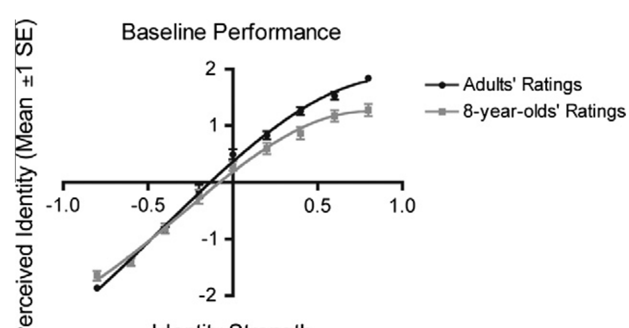

Fig. 3. Results from the baseline phase for adults and 8-year-olds. On the *x*-axis is the Identity Strength of the stimuli, ranging from 100% Dan (-1.0) to 100% Jim (1.0), with 0 = average face. On the *y*-axis is the mean Perceived Identity rating: participants responded whether a face was Jim (2), Jim's brother (1), Dan (-2), Dan's brother (-1), or none of the above (0).

age difference in their perception of the average face, t(46) = 1.61, p = 0.11, d = 0.64. Additionally, there was no difference in the point of subjective equality (PSE), that is the identity strength where subjects in each age group had a 50:50 probability of rating the face as Jim or Dan. We used nonlinear regression to calculate the point of subjective equality (PSE) separately for adults and 8-year-olds. An analysis of the PSE indicated a positive bias, that is, a bias to respond "Jim", in both adults ($M = 0.36$, SEM = 0.07), t(23) = 5.18, p < .001, d = 1.06, and 8-year-olds ($M = 0.18$, SEM = 0.07), t(23) = 2.81, p = .01, d = 0.57, but critically, no difference in the magnitude of this bias between adults and 8-year-olds, t(46) = 1.88, p = .07, d = 0.81.

The interaction in the original ANOVA appears to have arisen from a main effect of age with Jim faces, F(1, 46) = 16.78, p < 0.001, partial $\eta^2 = 0.27$, but not with Dan faces, F(1, 46) = 0.20, p = 0.66, partial $\eta^2 = 0.004$. As can be seen from Fig. 3, children tended to give lower scores (i.e., weaker perceived identity) to Jim faces than adults did, consistent with previous findings of immature processing of facial identity at this age (e.g., Baudouin et al., 2010; Mondloch et al., 2002; Nishimura, Maurer, & Gao, 2009).

3.2. Aftereffects

Fig. 4 shows the shifts (relative to baseline) in the perceived identity of the average face after adaptation to the anti-face at four different durations, plotted on a log scale. The effect of adaptation was examined by comparing the extent to which perceived identity was biased in the expected direction (i.e. opposite to the adapting face) in 8-year-olds and adults, after 1, 2, 4 and 8 s of adaptation. A repeated-measures ANOVA revealed a significant main effect of duration, F(3, 138) = 32.22, p < 0.001, partial $\eta^2 = 0.41$, indicating greater identity aftereffects after longer adaptation durations (see Fig. 4). This pattern was confirmed by a significant linear trend between the size of the shift and (log) duration, F(1, 46) = 112.91, p < 0.001, partial $\eta^2 = 0.71$, which indicates a logarithmic increase in the size of the aftereffect with longer adaptation durations. However, there was no main effect of age, F(1, 46) = 0.15, p = 0.70, partial $\eta^2 = 0.003$, and no duration $\times$ age interaction, F(3, 138) = 1.33, p = 0.27, partial $\eta^2 = 0.03$, results indicating that the temporal dynamics and strength of adaptation were not different at the two ages.

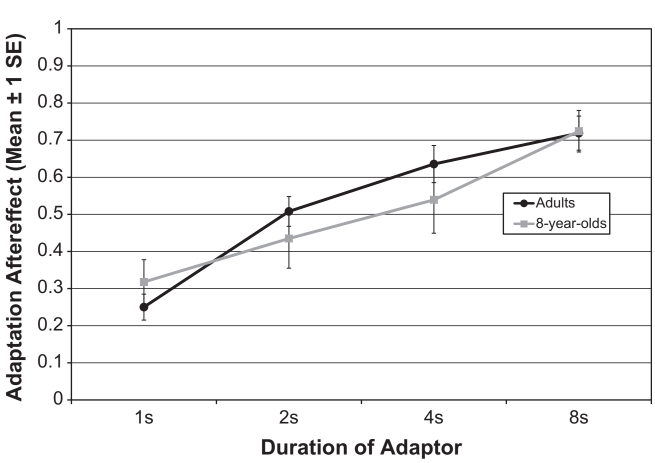

Fig. 4. Shift in the perceived identity strength of the average face at each adapting duration for adults and 8-year-olds. Values of zero represent no shift; positive values represent shifts in the expected direction (e.g., responding "Dan" after adapting to "anti-Dan").

To determine whether adaptation shifted perceived identity at every adapting duration, we conducted post hoc paired samples *t*-tests with a Bonferonni correction comparing recognition of the average face (0% identity strength) with and without adaptation, separately for 8-year-olds and adults. For both age groups, perceived identity was biased away from the adapting face at all adaptation durations tested, all ps < 0.01.

4. Discussion

The findings of the present study reveal that the perception of a face can be biased in the direction opposite to the adapting face after as little as one second of adaptation, and that the effect is as strong in 8-year-olds as it is in adults. Moreover, there was a similar logarithmic increase in the aftereffect with longer adapting durations in 8-year-olds and adults, replicating the findings from two previous studies with adults (Leopold et al., 2005; Rhodes, Jeffery et al., 2007). These findings suggest that by 8 years of age, the temporal dynamics of face identity aftereffects are similar in children and adults, at least for short-term adaptation. Like adults, children appear to use an adaptive coding mechanism that dynamically calibrates neuronal responses to the range of values most commonly and recently experienced (Rhodes, Maloney, Turner, & Ewing, 2007).

The present study reveals that 8-year-olds demonstrate similar identity aftereffects to adults in response to varying adapting durations. Thus, contrary to our hypothesis, we found no evidence that the norm in 8-year-olds' face-space is more malleable or prone to transient adaptation than that of adults, as measured by the influence of adapting duration. However, the finding that the other-race effect can be reversed in children up to 9 years of age (Sangrigoli et al., 2005) suggests that some neural plasticity in the face processing system exists in childhood that is not evident in adulthood. One interpretation of this plasticity, then, is that although transient adaptation effects may be similar for 8-year-olds and adults, repeated exposure over the course of days or months may have longer-lasting effects in children than adults, which may lead to more permanent changes to the norm over time. Such an effect may occur not because the coding of faces differs qualitatively between children and adults, but simply because the face-space of children contains fewer faces than that of adults, and therefore each new face carries greater weight in altering the average and hence has more permanent effects. The boundaries for relating faces to that average may also be ill-defined so that stimuli that violate the first-order relations of a face (e.g., by having one eye much higher than the other) can induce large adaptation aftereffects, as they do in children 6–12 years but not adolescents (Hills et al., 2010) or adults (Robbins et al., 2007).

The findings from the present study suggest that children's immaturities on tests of face processing are not in norm-based coding per se, nor in how quickly the norm can be updated dynamically. The group of studies revealing adult-like face aftereffects by age 8 years (Anzures et al., 2009; Jeffery et al., 2010; Nishimura et al., 2008), including the present study, appears contradictory to the group of studies suggesting slow development of face processing, such as on tasks that require sensitivity to feature spacing (e.g., Mondloch et al., 2002). One potential source of this difference is that adaptation paradigms assess a shift in the perception of the average face, for which there is no "correct" identity, thereby eliminating potential baseline differences between adults and children. Another potential source is the method by which adaptors are created – anti-faces are created such that all structural deviations from the average are manipulated simultaneously. These manipulations would map onto any dimension that only adults utilize but children do not, as well as those dimensions that are represented in the face-space of both children and adults. The latter may suffice to produce similar aftereffects in children and adults. Other tasks (e.g. configural processing) might rely specifically on a dimension (e.g., spatial relation among facial features) that is not yet mature in children but stable in adults, thereby revealing developmental differences.

Although no differences were observed in the strength of the identity aftereffect, 8-year-olds gave lower identity ratings (i.e. weaker perceived identity) to the Jim faces than adults in the baseline condition, a finding that is consistent with previous reports that adults are more accurate at perceiving faces than children 8 years of age (e.g., Mondloch et al., 2002; Nishimura et al., 2008). What continues to develop beyond 8 years of age likely lies, not in the coding of facial identities relative to the norm, but rather, in more general visuo-cognitive abilities; in the number, fidelity, stability, and differentiation of the mental representation of the individual identities; and/or in distinguishing the dimensions themselves, including the consistency with which the dimensions are used (McKone, Crookes, & Kanwisher, 2009; Mondloch, Maurer, & Ahola, 2006; Nishimura et al., 2009; Tanaka & Corneille, 2007). The neuroimaging evidence for changes after age 8 in the brain regions involved in face processing (Cohen Kadosh et al., 2010; Golarai et al., 2007, 2009; Scherf et al., 2007) suggests that something in addition to general visuo-cognitive changes is involved. Recent studies examining face processing in individuals with congenital prosopagnosia, a specific disorder in recognizing faces, suggest that the representation of the norm and individual identities may be supported by different neural substrates, with more posterior cortical regions being involved in the representation of average and more anterior regions being involved in the representation of individual facial identities (Behrmann, Avidan, Gao, & Black, 2007; Nishimura, Doyle, Humphreys, & Behrmann, 2010; Thomas et al., 2009). Therefore, one possible avenue for future research is to compare the development of the more anterior versus posterior cortical regions implicated in face processing.

5. Conclusion

In summary, we found that the temporal dynamics of identity aftereffects are the same in adults and 8-year-old children. At both ages, exposure to one identity caused an average face to look more like the opposite identity, as would be expected by norm-based coding. Regardless of age, shifts occurred rapidly, after as little as 1 s of adaptation, and then grew logarithmically with longer adaptor durations. Thus, the immaturities in performance on face processing tasks at 8 years of age must arise form another source.

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