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Developmental changes in face recognition during childhood: Evidence from upright and inverted faces

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ABSTRACT

Adults are experts at recognizing faces but there is controversy about how this ability develops with age. We assessed 6- to 12-year-olds and adults using a digitized version of the Benton Face Recognition Test, a sensitive tool for assessing face perception abilities. Children's response times for correct responses did not decrease between ages 6 and 12, for either upright or inverted faces, but were significantly longer than those of adults for both face types. Accuracy improved between ages 6 and 12, significantly more for upright than inverted faces. Inverted face recognition improved slowly until late childhood, whereas there was a large improvement in upright face recognition between ages 6 and 8, with a further enhancement after age 12. These results provide further evidence that during childhood face processing undergoes protracted development and becomes increasingly tuned to upright faces.

1. Introduction

It is generally accepted that children are poorer than adults at recognizing upright faces and that their face recognition abilities take years to reach an adult level of expertise (Blaney & Winograd, 1978; Carey, 1992; Carey, Diamond, & Woods, 1980; Flin, 1985). Carey and Diamond (1977) found that 6-year-olds were 12% less accurate at recognizing upright faces than 8-year-olds, who were in turn

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7% worse than 10-year-olds (for similar results, see Feinman & Entwhistle, 1976; Goldstein & Chance, 1964). In a follow-up experiment, Carey et al. (1980) used the Benton and Van Allen test (1968) to assess the development of 6- to 16-year-olds' ability to memorize unfamiliar upright faces and to discriminate them from new pictures. They found non-linear increases in accuracy: gradual improvement to age 10, a plateau between 10 and 14, and further improvement by age 16 (see Lawrence et al., 2008, for similar results). In many studies, pre-adolescence was found to be a period when performance stabilizes (Carey et al., 1980; Lawrence et al., 2008) or temporarily decreases (Carey, 1992; Ellis, 1992; Ellis & Flin, 1990; Flin, 1980, 1985; Flin & Dziurawiec, 1989; for a review, see Chung & Thomson, 1995). Yet, the age at which children's performance reaches adult levels for upright faces remains uncertain, with estimates ranging from 10 years (Carey, 1992), to 11 years (Feinman & Entwhistle, 1976); 16 years (Carey et al., 1980, and after 30 years (Germine, Duchaine, & Nakayama, 2011).

Some researchers have attributed children's lower accuracy to an immaturity of general cognitive skills such as attention or memory, rather than to a specific immaturity in face processing, at least after 4 years of age (e.g., Crookes & McKone, 2009; McKone & Boyer, 2006; Pellicano, Rhodes, & Peters, 2006; Want, Pascalis, Coleman, & Blades, 2003). Other researchers have posited that children of preschool or early school age process faces differently than do adults (Brace et al., 2001; Carey et al., 1977; Mondloch, Leis, & Maurer, 2006; Schwarzer, 2000) or that during development they use the same face-specific processes as adults to process upright faces but to a different extent (Baudouin, Gallay, Durand, & Robichon, 2010; Carey et al., 1980, 1992; Carey & Diamond, 1994; Freire & Lee, 2001; Mondloch, Le Grand, & Maurer, 2002; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Leis, et al., 2006; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007).

In principle, support for either a general component or a component specific to upright faces to explain increased face recognition ability with age could come from the comparison of developmental trajectories for processing faces and control visual stimuli. A general component would be supported by similar changes with age for both types of stimuli (i.e., parallel improvement) whereas a component specific to upright faces would be supported by greater change with age for faces than for the control stimuli (with more improvement for upright faces). The most commonly used control stimulus has been the same face presented upside-down. An inverted face has many advantages over a non-face object. First, the visual stimuli compared are identical in terms of low-level visual properties and complexity, with only an inversion of the orientation of the image. Second, any tuning by experience of components specific to upright faces should only improve the processing of this face category. Third, there is a large literature indicating that adult face processing skill plummets when the stimulus is inverted (Rossion, 2008), an effect much larger for faces than common object categories (Yin, 1969).

Only a few authors have compared recognition of upright and inverted faces across age groups. Carey and Diamond (1977) found substantial improvements between age 6 and 10 in accuracy for upright faces, but virtually no change for inverted faces: the improvement with age was 19% for upright faces but only 4% for inverted faces (see Flin, 1985; for similar results). Brace et al. (2001) examined upright and inverted face recognition in children aged 2–11. They found better recognition of upright than inverted faces only from age 6 and a paradoxically reversed pattern (better recognition for inverted than upright faces) in children aged 2–4. However children were tested on only 3 upright trials and 3 inverted trials, and interpretation is difficult because accuracy was close to, or at, ceiling after age 6. Unfortunately, none of these studies included an adult group to track the processing of inverted faces to maturity and none used fine gradations of age. The only exception is a study by Germine et al. (2011) that tracked the ability to recognize children's faces in upright and inverted orientations in a large sample of 12- to 64-year-olds. The authors found the upright and inverted functions peaking at 30.1 and 23.5 years, respectively.

Because the study by Germine et al. (2011) did not include participants below 12 years of age and because of the controversy about the nature of the changes in middle childhood, we designed the current study to compare adults to children distributed across the age range 6–12 on their abilities to recognize both upright and inverted faces. We focused on this age range because this is the period for which there is a major disagreement about the cause of improvements in accuracy with age (Crookes & McKone, 2009; Mondloch et al., 2002). We also included an analysis in which we divided age into finer-grained steps by analyzing age in months rather than years. We chose a digitized version of the well-known Benton Face Recognition Test (BFRT; Benton, Sivan, Hamsher, Vereny, & Spreen, 1983) to contrast the developmental trajectories of upright and inverted face recognition. This task offered many advantages. First, it requires matching facial identities despite changes in lighting and viewpoint and thus requires processing identity rather than simple image matching. To further de-emphasize image matching, we introduced a difference in size between the target and matching faces. Second, the digitized Benton task and child-friendly touch screen allowed the collection of not only accuracy data but also response times. In adults, inversion effects are reflected in both accuracy and response times (Goffaux & Rossion, 2007). Third, the Benton task is composed of more trials than many other measures used with children (Brace et al., 2001; Carey & Diamond, 1977; Flin, 1985). Fourth, it is commonly used with brain damaged adults by clinicians and cognitive neuropsychologists (Busigny & Rossion, 2010; Sergent & Signoret, 1992). It has extensive normative data for adults and does not produce ceiling effects in normal participants. Finally, the task is advantageous because of its simple instructions, which can be understood easily even by young children. However, the BFRT test has been criticized by Duchaine and Weidenfield (2003) and Duchaine and Nakayama (2004) mainly because their patients with face recognition disorder scored within the normal range on measures of accuracy while some participants with normal vision scored in the borderline range when normal face processing was prevented by occluding the nose, mouth, and eyes (but not eyebrows). However, it is important to note that this issue is not specific to the BFRT but to any face matching task with simultaneous presentation of stimuli, as acknowledged by Benton himself (1980). Moreover, this criticism does not apply when response times are collected, in addition to accuracy, as in the present study, because individuals with acquired face recognition disorder score below normal range and/or are abnormally slow (Busigny & Rossion, 2010), as was likely also the case for the normal adults tested with obscured features (Duchaine & Nakayama, 2004 did not measure response times).

In our digitized version of the task, a male or female face was presented centred on a black background above 6 simultaneously presented choice faces, one (Part 1) or three (Part 2) of which had the same identity as the target face, either with the same viewpoint (Part 1) or with changed viewpoint and lighting (Part 2). Unlike the original Benton task, target and probe faces were of different size to encourage matching on the basis of identity rather than image. Faces were presented upright and inverted in separate blocks. By digitizing the test and using a touch screen, we were able to record both accuracy (% of correct responses) and response times from children as young as 6.

2. Methods

2.1. Participants

Participants were 108 6–12-year-olds (49 males; mean age 111 months, $SD = 21$, range 72–150 months), recruited from middle-class schools and Boy Scout organizations in Belgium. Their ages, for some analyses, were divided into tertiles (T1 $n = 36$, 19 males, 72–100 months; T2 $n = 36$, 18 males, 100–123 months; T3 $n = 36$, 22 males, 123–150 months). Thirty-six undergraduate students enrolled in an introductory psychology course (11 males; mean age 19 years, $SD = 1$; range 212–261 months) also participated. They received course credit for participation. Participants who required optical correction wore their normal correction while participating.

2.2. Stimuli

We created the upright digitized version of the Benton test by scanning the original panels of the test and extracting each face using Adobe Photoshop 7.0. The target and the 6 probe faces, initially presented on two different panels, were pasted onto a single dark grey background panel, which subtended approximately $40^{\circ} \times 30^{\circ}$ of visual angle when viewed from 40 cm. Unlike the original test, the target and probe faces were differentiated by displaying the target faces at a slightly larger size (133×200 pixels; $5^{\circ} \times 7.5^{\circ}$ of visual angle) than the probe faces (129×150 pixels; $6.5^{\circ} \times 7.54^{\circ}$ of visual angle) to encourage processing of facial identity rather than stimulus matching. As in the original test, stimuli were greyscale male or female faces with neutral expressions and unfamiliar to the participants (Fig. 1A). Targets (Part 1: $n = 6$ [3F, 3M]; Part 2: $n = 16$ [8F, 8M]) were always full-front views displayed

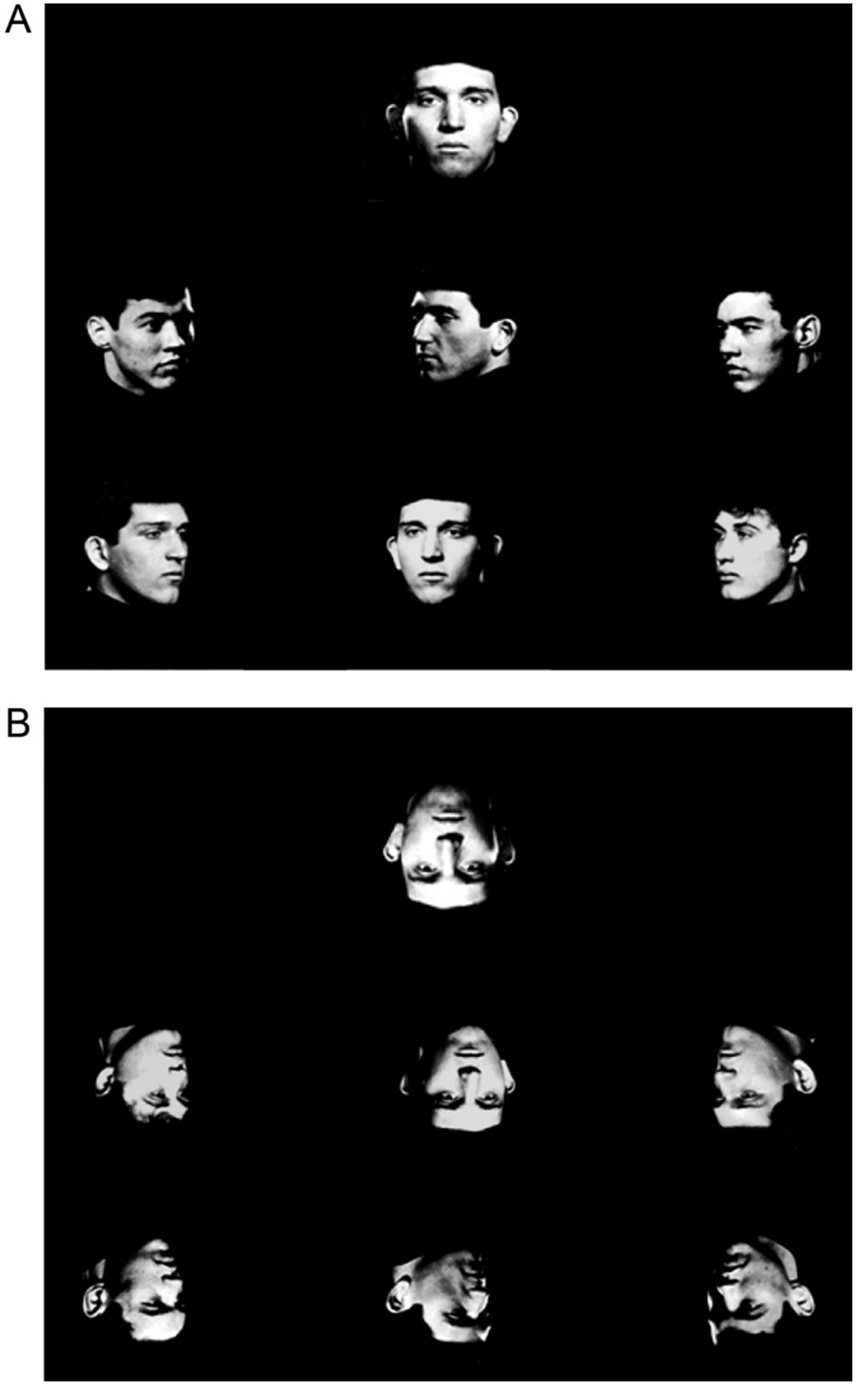


Fig. 1. Examples of trials composing the second part (Part 2) of the upright and inverted condition of the digitized Benton test. Here participants had to match the target face with 3 probes presented under different points of view and lightning.

in the middle of the upper part of the frame. Probes were organized in two rows of three faces below the target face and were either full-front view taken with the same lighting (Part 1) or ¾ view taken under different lighting (Part 2). Images were rotated by 180° to create the inverted version of the test (Fig. 1B).

2.3. Procedure

Stimuli were presented from a laptop computer (Dell Latitude) controlled by E-prime 1.1. The images appeared on a 12.1-in. Elo Entuitive Touchmonitor for children, who were seated 40 cm from the touch screen. Adults were tested with the same laptop but connected to a 22-in. NEC touch monitor on which the images were slightly larger. To compensate and keep equal the retinal size of the images, adults were seated 46 cm from the touch screen.

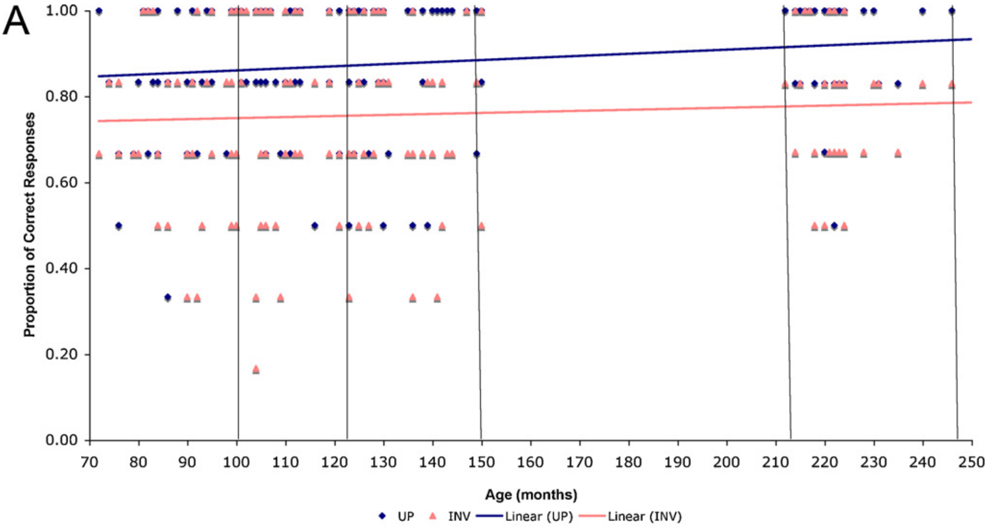
Faces were projected upright and upside-down in separate blocks with order of blocks counterbalanced across participants. As in the original Benton test, each block (upright and inverted) was composed of 22 trials split in two parts (Part 1 and Part 2). Participants were first given one example using different faces as in Part 1 and instructed to match as fast as possible the face at the top of the screen to the same face presented among 5 distractors, all of slightly smaller size. Then they were asked to perform the 6 trials of Part 1 in the exact same way. Before starting the 16 trials of Part 2, participants were told that this time they would have to match the target to three different exemplars of the same face, again slightly smaller, but also presented from another point of view and with different lighting. Thus, for both the upright and inverted conditions, participants produced 6 responses in Part 1 (1 matching exemplar × 6 trials) and 48 responses in Part 2 (3 matching exemplars × 16 trials). Trials were separated from each other by blank intervals of 500 ms. For each block (upright and inverted), pauses were included after the first part of the test and in the middle of the second part of the test.

3. Results

We excluded from response time data any value greater than 3 standard deviations from the individual's mean. The number of excluded data points was similar across tertiles and conditions and ranged from 3 to 8%. A comparison confirmed that analyses were comparable whether or not outlier were included.

As shown in Fig. 2, participants' accuracy was at or close to ceiling in Part 1. Nevertheless, participants were more accurate in the upright (T1: 85%; T2: 87%: T3: 89%; adults: 92%) than in the inverted condition (T1: 74%; T2: 75%: T3: 77%; adults: 78%). They typically made 0–1 error for upright faces and 1–2 errors for inverted faces. We did not conduct statistical analyses for these data because of the small number of trials. Nevertheless, it is interesting to note that participants at all ages were faster in the upright (T1: 6257 ms; T2: 4060 ms; T3: 3761 ms; adults: 2754 ms) than in the inverted condition (T1: 6366 ms; T2: 6343 ms; T3: 5808 ms; adults: 4240 ms).

In Part 2, involving three faces matching in identity and six distractors, with variations in size, viewpoint, and lighting. The youngest children (T1) performed statistically above chance both in the upright and the inverted condition (two-tailed one-sample *t*-test). In the upright condition $t(35) = 5.54$, $p < .0001$; in the inverted condition $t(35) = 4.269$, $p < .0001$)—as did every other age group (Fig. 3). As illustrated in Fig. 4 (top panel), accuracy increased with age for both upright and inverted faces, with a larger difference between the two orientations in the older age groups than in the youngest age group. The difference in accuracy for upright and inverted faces increased from only 3% in T1 to 9% during T2 and T3, and to 14% in the adult group (Fig. 3). A repeated-measures analysis of variance (ANOVA) on accuracy (% correct) in Part 2 with the *orientation* of the face (upright *vs.* inverted) as a within-subject variable and the *age tertile* (T1 *vs.* T2 *vs.* T3 *vs.* adults) as the between-subject variable confirmed an increasing difference with age between upright and inverted conditions. There was a main effect of orientation. $F(1, 140) = 170.742$, $p < .0001$; partial $\eta^2 = .549$ [better for upright], a main effect of age. $F(3, 140) = 22.397$, $p < .0001$; partial $\eta^2 = .324$ [better for older] and an interaction between age and orientation. $F(3, 140) = 10.427$, $p < .0001$; partial $\eta^2 = .183$. Simple ANOVAs for accuracy showed a main effect of age for upright condition, $F(3, 143) = 25.634$, $p < .0001$, partial $\eta^2 = .355$, and inverted condition, $F(3, 143) = 7.69$, $p < .0001$, partial $\eta^2 = .141$. Planned comparisons of adjacent tertiles



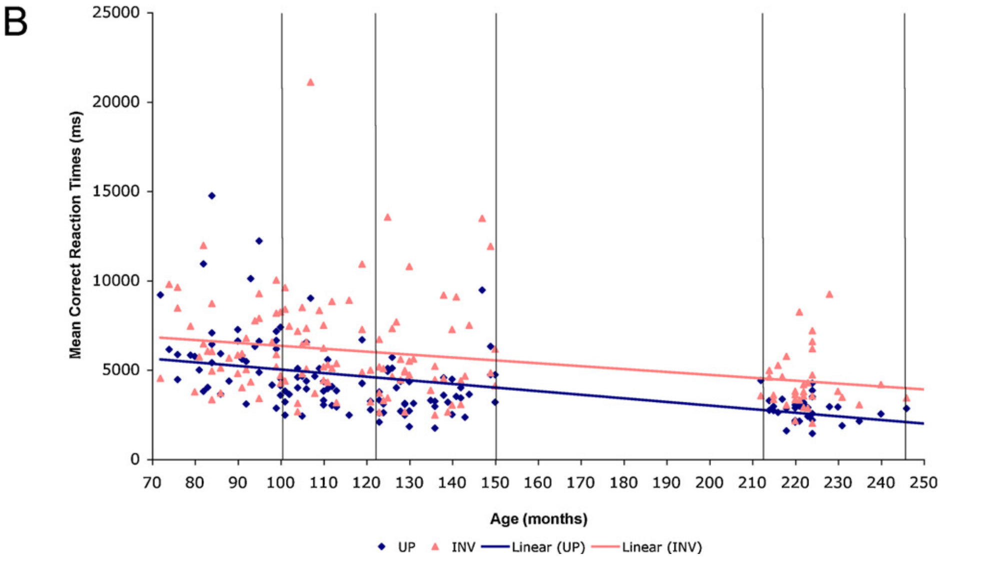


Fig. 2. Mean proportion of correct responses (top panel) and mean correct response times (ms) (bottom panel) in the first part of the digitized Benton task when matching upright (◊) and inverted (△) faces as a function of age at test (months). Vertical lines represent the boundaries between the different age groups (T1 *vs*. T2 *vs*. T3 *vs*. adults). The solid lines represent the best-fitting linear regressions for upright (blue) and inverted (pink) faces. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

(two-tailed independent *t*-tests with a Bonferroni correction) for each condition indicated different trends. In the upright condition, accuracy differed significantly between the first and the second tertile, $t(70) = -3.767$, $p = .001$; Cohen's $d = -0.94$, and the third and the adult tertile. $t(70) = -3.284$, $p = .008$; Cohen's $d = -0.82$, but not between the second and the third tertile. $t(70) = -1.526$, $p = .716$; Cohen's $d = -0.35$. In the inverted condition, no adjacent tertiles differed significantly from each other. These patterns were confirmed in supplementary bootstrap analyses with age defined in months in order to detect differences at a finer scale (Fig. 4). These analyses were performed on the entire data set as well

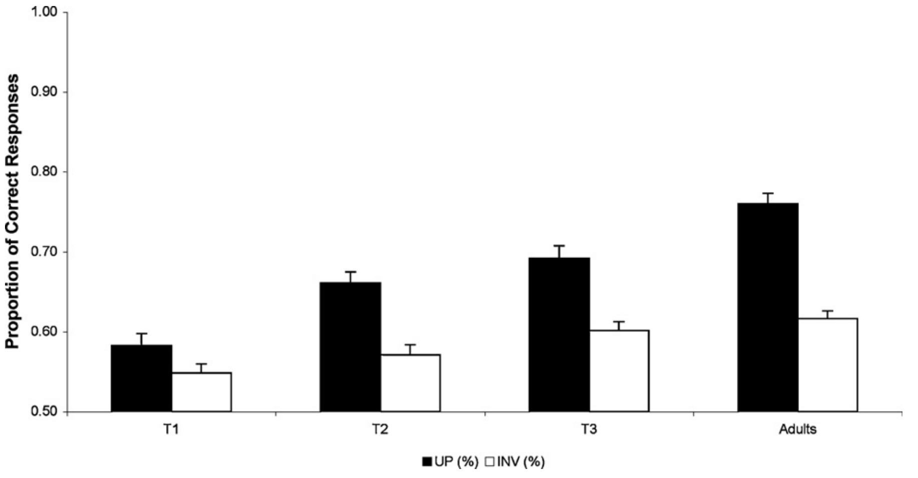


Fig. 3. Mean proportion of correct responses in the second part of the digitized Benton task when matching upright and inverted faces for the four groups (T1: 72–100 months; T2: 100–123 months; T3: 123–150 months; adults: 212–261 months).

as on each *age tertile* considered separately (T1, T2, T3, and adults). Across all data, the slope of the function relating accuracy to age was significantly steeper for upright than inverted faces. Indeed the slope of the inverted function ($y = .0005x + .52$) fell outside the 95% confidence interval [.0009–.0014] defined for the upright function ($y = .0011x + .51$). We found a similar difference within T1: the slope for upright faces ($y = .0057x + .08$) was significantly steeper than the slope for inverted faces ($y = .0021x + .36$; 95% confidence interval = [.0022–.0098]). Within the other age periods, the slopes for upright and inverted faces fell inside the 95% confidence interval.

A repeated-measures ANOVA on response times (ms) for correct responses was performed, with orientation (upright *vs.* inverted) as a within-subject variable and age (T1 *vs.* T2 *vs.* T3 *vs.* Adults) as a between-subjects variable. We found a main effect of age, $F(3, 140) = 10.085$, $p < .0001$; partial $\eta^2 = .178$, as well as a main effect of orientation, with upright faces processed faster than inverted faces, $F(1, 140) = 18.645$, $p < .0001$; partial $\eta^2 = .118$. The advantage of upright over inverted faces did not vary from childhood to adulthood since the interaction between age and orientation failed to reach significance, $F(3, 140) = 1.408$, $p = .243$; partial $\eta^2 = .029$ (Fig. 4, bottom panel). Planned comparisons of adjacent tertiles (independent t-tests with a Bonferroni correction) performed on the conditions separately indicate no significant difference between first and second tertile, for upright condition, $t(70) = 1.563$, $p = 1.000$ (Cohen's $d = .37$), or for inverted condition, $t(70) = -.655$, $p = 1.000$ (Cohen's $d = -0.15$). Nor was there a difference between second and third tertile, $t(70) = -.551$, $p = 1.000$ (Cohen's $d = -0.13$) for upright condition and $t(70) = .312$, $p = 1.000$ (Cohen's $d = .07$) for inverted condition. However there was a significant difference between the third tertile and the adult group, $t(70) = 4.391$, $p < .0001$ (Cohen's $d = 1.03$) and $t(70) = 3.371$, $p = .005$ (Cohen's $d = .79$) for the upright and inverted conditions respectively. Thus speed in recognizing faces did not change greatly between ages 6 and 12. However adults were significantly faster than children for both upright and inverted faces. This pattern is consistent with evidence of better control of attention and faster information processing in adults than in children (Levy, 1980).

4. Discussion

In this study, participants were asked to match the identity of the upright and inverted faces of the digitized Benton Face Recognition Test. The task appears to be a sensitive measure for tracking developmental differences as the youngest participants performed above chance even in the harder inverted condition, yet adults were not at ceiling for the easier upright condition. Face stimuli varied in terms of lighting, point of view, and size, variations that mitigated against solving the task by matching

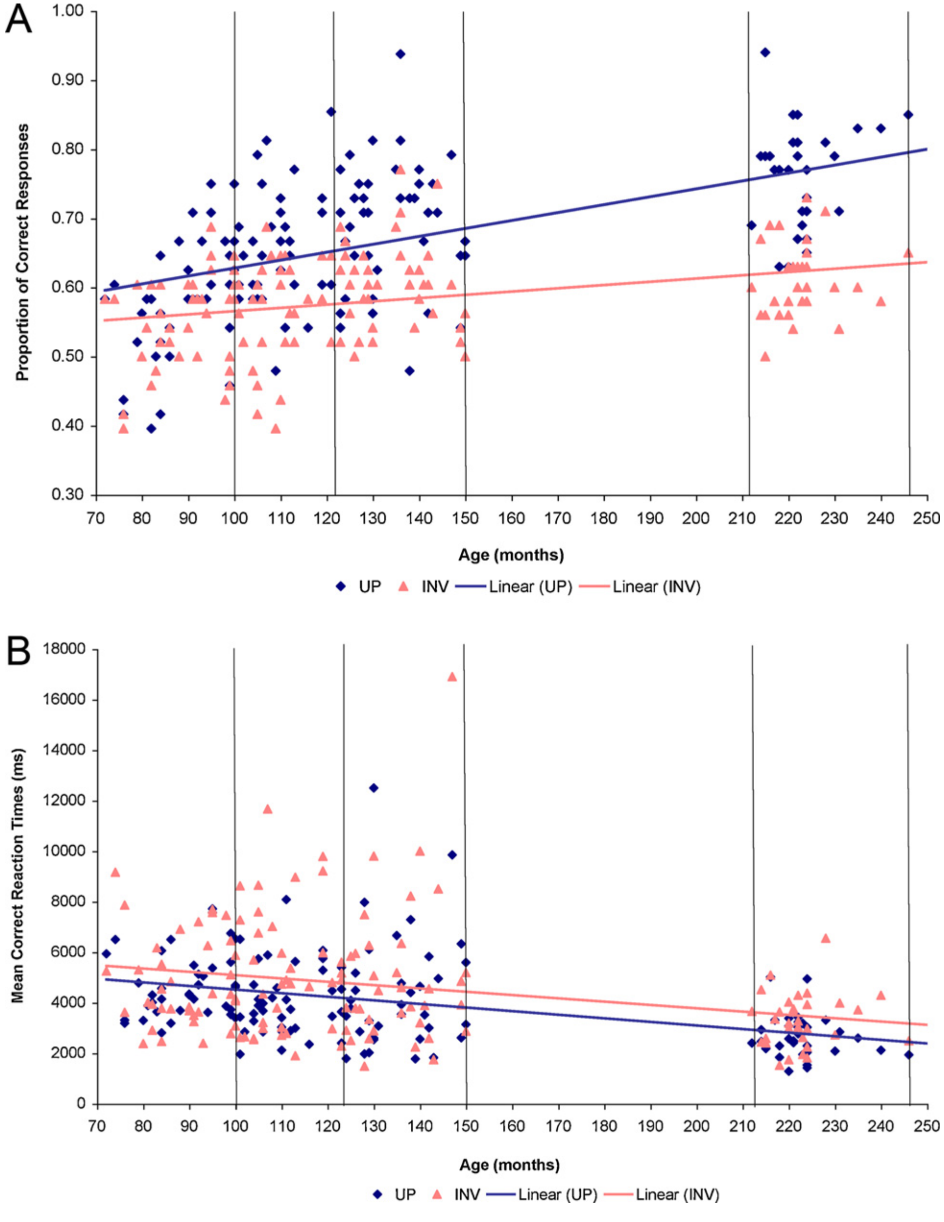


Fig. 4. Mean proportion of correct responses (top) and mean correct response times (ms) (bottom) in the second part of the digitized Benton task when matching upright (◊) and inverted (△) faces as a function of age (months). Vertical lines represent the boundaries between the different age groups (T1 *vs.* T2 *vs.* T3 *vs.* adults). The solid lines represent the best-fitting linear regressions for upright (blue) and inverted (pink) faces. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

images, although this variation prevents direct comparisons with previous studies that did not vary all three properties (Carey et al., 1980; Ellis, 1992; Lawrence et al., 2008).

Our results suggest that both general cognitive mechanisms and mechanisms specifically tuned to upright faces contribute to children's improvement with age in recognizing the identity of faces. On the one hand, response times support a general explanation: At all ages participants were faster with upright than inverted faces and the difference between these conditions did not increase with age. Thus, response times did not reveal any developmental changes specific to upright faces: Adults were faster overall than children, regardless of whether the faces were upright or inverted. Faster response times in adults are unlikely to have resulted from limited range in adults (Crookes & McKone, 2009) since response times at all ages were fairly long, well above the minimum time needed to make a motor response. Instead it seems likely that adults' faster response times result from general cognitive and/or visual improvements, such as improvements in the ability to use deliberate task strategies, to concentrate on the task and avoid distractions, to narrow the focus of visual attention, and to make fine discrimination (Crookes & McKone, 2009).

Conversely, improvements in accuracy point to changes in a mechanism or mechanisms that by adulthood are tuned to upright faces, likely interacting with general cognitive and/or visual improvements. Participants of all ages were more accurate with upright than inverted faces, but the size of the difference between these two conditions increased with age (3% more accurate for the youngest tertile; 14% for adults). Consistent with previous studies (Carey & Diamond, 1977; Feinman & Entwhistle, 1976), improvement for upright faces was the largest between ages 6 and 8, with smaller changes between 8 and 12. Accuracy also improved for inverted faces during these age periods, but to a lesser extent (Brooks & Goldstein, 1963; Carey & Diamond, 1977; Flin, 1985). This pattern of results supports the involvement of a mechanism that is becoming tuned by experience with upright faces, particularly between ages 6 and 8. It is less clear that the changes between ages 8 and 12 arise from processes specific to upright faces since the improvements we observed within this age period were of similar magnitude for upright and inverted faces. On the one hand, the possibility that the changes between 8 and 18 result from general cognitive or visual changes, rather than from a process that becomes increasingly tuned by experience with upright faces, is consistent with evidence that young adults are 14% more accurate than 8-year-olds in matching the identity of both upright human and monkey faces (Mondloch, Maurer, & Ahola, 2006). On the other hand, recent data suggest there may be an additional period after age 18 with improvements specific to upright faces: between age 20 and 30, upright face recognition improves while there was no change for inverted faces (Germine et al., 2011).

Crookes and McKone (2009) recently concluded that full maturity of face processing is reached early in childhood, by 5–7 years, with subsequent improvement in performance resulting only from general cognitive development. They based their arguments on previous research indicating that holistic face processing is adult-like by 4–6 years of age (Carey & Diamond, 1994; de Heering, Houthuys, & Rossion, 2007; Mondloch et al., 2007; Pellicano & Rhodes, 2003; Pellicano et al., 2006; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). However, it might be that children process faces holistically from age 4 but that this component matures slowly thereafter; for firm conclusions a larger age span and other sensitive measures of the development of face processing, such as event-related potentials (Kuefner, de Heering, Jacques, Palmero-Soler, & Rossion, 2010) and neuroimaging (Golorai et al., 2007) may be necessary. Also, the authors' conclusions based on their own experimental data may need to be moderated because of the ceiling effect for upright faces in this task after age 8 (Experiment 1 in Crookes & McKone, 2009), as well as the greater difference in performance for upright *vs.* inverted faces for adults than for 7-year-olds on similar tasks (Experiment 2).

In summary, we found that, like adults, children from 6 years of age process upright faces better and faster than inverted faces. Children's response times were generally slower than adults' both in the upright and inverted condition, a pattern pointing to explanations based on general visual and/or cognitive explanations of improvement in performance with age. In contrast, the data for accuracy support an additional explanation of developmental changes that are specific to upright faces, at least between ages 6 and 8. Future studies could probe the exact nature of these mechanisms. For example, one could correlate measures of face recognition of the type used here with the magnitude of children's holistic processing, with their ability to perceive subtle spacing manipulations between facial features, with measures of visual development (e.g., vernier acuity, Skoczenski & Norcia, 2002; thresholds for contour integration, Kovacs, Kozma, Feher, & Benedek, 1999), and with measures of cognitive skills such as executive function and selective attention. In the same vein, one could probe whether the rate of development is similar for categories of faces with which the child has more (e.g., own age faces) and less experience (e.g., elderly faces, infants' faces). A similar rate of improvement with age across categories would favor a general explanation whereas faster improvement for the familiar category, like that found for upright faces in the present study, would support the role of mechanisms tuned by specific experience.

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References

Baudouin, J. Y., Gallay, M., Durand, K., & Robichon, F. (2010). The development of perceptual sensitivity to second-order facial relations in children. *Journal of Experimental Child Psychology*, *107*, 195–206.

Benton, A. L. (1980). The neuropsychology of facial recognition. *The American Psychologist*, *35*, 176–186.

Benton, A. L., Sivan, A. B., Hamsher, K., Vareny, N. R., & Spreen, O. (1983). Facial recognition: Stimulus and multiple choice pictures. In A. L. Benton, A. B. Sivan, K. D. S. Hamsher, N. R. Varney, & O. Speen (Eds.), *Contributions to neuropsychological assessment* (pp. 30–40). New York: Oxford University Press.

Benton, A. L., & Van Allen, M. W. (1968). Impairment in facial recognition in patients with cerebral disease. *Cortex*, *4*, 344–358.

Blaney, R. L., & Winograd, E. (1978). Developmental differences in children's recognition memory for faces. *Developmental Psychology*, *14*, 441–442.

Brace, N. A., Hole, G. J., Kemp, R. I., Pike, G. E., Van Duuren, M., & Norgate, L. (2001). Developmental changes in the effect of inversion: Using a picture book to investigate face recognition. *Perception*, *30*, 85–94.

Brooks, R. M., & Goldstein, A. V. (1963). Recognition by children of inverted photographs of faces. *Child Development*, *34*, 1033–1040.

Busigny, T., & Rossion, B. (2010). Acquired prosopagnosia abolishes the face inversion effect. *Cortex*, *46*, 965–981.

Carey, S. (1992). Becoming a face expert. *Philosophical Transactions of the Royal Society of London, B*, *335*, 95–103.

Carey, S., & Diamond, R. (1977). From piecemeal to configurational representation of faces. *Science*, *195*, 312–314.

Carey, S., & Diamond, R. (1994). Are faces perceived as configurations more by adults than by children? *Visual Cognition*, *1*, 253–274.

Carey, S., Diamond, R., & Woods, B. (1980). The development of face recognition—a maturational component? *Developmental Psychology*, *16*, 257–269.

Chung, M., & Thomson, D. M. (1995). Development of face recognition. *British Journal of Psychology*, *86*, 55–87.

Crookes, K., & McKone, E. (2009). Early maturity of face recognition. No childhood development of holistic processing, novel face encoding, or face-space. *Cognition*, *111*, 219–247.

de Heering, A., Houthuys, S., & Rossion, B. (2007). Holistic face processing is mature at 4 years of age: Evidence from the composite face effect. *Journal of Experimental Child Psychology*, *96*, 57–70.

Duchaine, B. C., & Nakayama, K. (2004). Developmental prosopagnosia and the Benton Facial Recognition Test. *Neurology*, *62*, 1219–1220.

Duchaine, B. C., & Weidenfield, A. (2003). An evaluation of two commonly used tests of unfamiliar face recognition. *Neuropsychologia*, *41*, 713–720.

Ellis, H. D. (1992). The development of face processing skills. *Philosophical Transactions of the Royal Society of London*, *335*, 105–111.

Ellis, H. D., & Flin, R. H. (1990). Encoding and storage effects in seven-year-olds' and ten-year-olds' memory for faces. *British Journal of Developmental Psychology*, *8*, 77–92.

Feinman, S., & Entwhistle, D. R. (1976). Children's ability to recognize other children's faces. *Child Development*, *47*, 506–510.

Flin, R. H. (1980). Age effects in children's memory for unfamiliar faces. *Developmental Psychology*, *16*, 373–374.

Flin, R. H. (1985). Development of face recognition: An encoding switch? *British Journal of Psychology*, *1*, 123–134.

Flin, R. H., & Dziurawiec, S. (1989). Developmental factors in facial processing. In A. W. Young, & H. D. Ellis (Eds.), *Handbook of research on facial processing* (pp. 105–111). North-Holland: Elsevier.

Freire, A., & Lee, K. (2001). Face recognition in 4- to 7-year-olds: Processing of configural, featural, and paraphernalia information. *Journal of Experimental Child Psychology*, *80*, 347–371.

Germine, L. T., Duchaine, B., & Nakayama, K. (2011). Where cognitive development and aging meet: Face learning ability peaks after age 30. *Cognition*, *118*, 201–210.

Goffaux, V., & Rossion, B. (2007). Face inversion disproportionately impairs the perception of vertical but not horizontal relations between features. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 995–1002.

Goldstein, A. G., & Chance, J. E. (1964). Recognition of children's faces. *Child Development*, *35*, 129–136.

Golorai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L., Gabrieli, J. D. E., et al. (2007). Differential development of high-level visual cortex correlates with category-specific recognition memory. *Nature Neuroscience*, *10*, 512–522.

Kovacs, I., Kozma, P., Feher, A., & Benedek, G. (1999). Late maturation of visual spatial integration in humans. *Proceedings of the National Academy of Sciences of the United States of America*, *96*, 12204–12209.

Kuefner, D., de Heering, A., Jacques, C., Palmero-Soler, E., & Rossion, B. (2010). Early visually evoked electrophysiological responses over the human brain (P1, N170) show stable patterns of face-sensitivity from 4 years to adulthood. *Frontiers in Human Neuroscience*, *3*, 67. doi:10.3389/neuro.09.067.2009

Lawrence, K., Bernstein, D., Pearson, R., Mandy, W., Campbell, R., & Skuse, D. (2008). Changing abilities in recognition of unfamiliar face photographs through childhood and adolescence: Performance on a test of non-verbal immediate memory (Warrington RMF) from 6 to 16 years. *Journal of Neuropsychology*, *2*, 27–45.

Levy, F. (1980). The development of sustained attention (vigilance) and inhibition in children: Some normative data. *Journal of Child Psychology and Psychiatry*, *21*, 77–84.

McKone, E., & Boyer, B. L. (2006). Sensitivity of 4-year-olds to featural and second-order relational changes in face distinctiveness. *Journal of Experimental Child Psychology*, *94*, 134–162.

Mondloch, C. J., Dobson, K. S., Parsons, P., & Maurer, D. (2004). Why 8-year-olds cannot tell the difference between Steve Martin and Paul Newman: Factors contributing to the slow development of sensitivity to the spacing of facial features. *Journal of Experimental Child Psychology*, *89*, 159–181.

Mondloch, C. J., Geldart, S., Maurer, D., & Le Grand, R. (2003). Developmental changes in face processing skills. *Journal of Experimental Child Psychology*, *86*, 67–84.

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, *31*, 553–566.

Mondloch, C. J., Leis, A., & Maurer, D. (2006). Recognizing the face of Johnny, Suzy, and me: Insensitivity to the spacing among features at 4 years of age. *Child Development*, *77*, 234–243.

Mondloch, C. J., Maurer, D., & Ahola, S. (2006). Becoming a face expert. *Psychological Science*, *17*, 930–934.

Mondloch, C. J., Pathman, T., Maurer, D., Le Grand, R., & de Schonen, S. (2007). The composite face effect in 6-year-old children: Evidence of adult like holistic face processing. *Visual Cognition*, *15*, 564–577.

Pellicano, E., & Rhodes, G. (2003). Holistic processing of faces in preschool children and adults. *Psychological Science*, *14*, 618–622.

Pellicano, E., Rhodes, G., & Peters, M. (2006). Are preschoolers sensitive to configural information in faces? *Developmental Science*, *9*, 270–277.

Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica*, *128*, 274–289.

Schwarzer, G. (2000). Development of face processing: The effect of face inversion. *Child Development*, *71*, 391–401.

Sergent, J., & Signoret, J. L. (1992). Varieties of functional deficits in prosopagnosia. *Cerebral Cortex*, *2*, 375–388.

Skoczenski, A. M., & Norcia, A. M. (2002). Late maturation of visual hyperacuity. *Psychological Science*, *13*, 537–541.

Tanaka, J., Kay, J., Grinnell, E., Stansfield, B., & Szechter, L. (1998). Face recognition in young children: when the whole is greater than the sum of its parts. *Visual Cognition*, *5*, 479–496.

Want, S. C., Pascalis, O., Coleman, M., & Blades, M. (2003). Face facts: is the development of face recognition in early and middle childhood really so special? In O. Pascalis, & A. Slater (Eds.), *The development of face processing in infancy and childhood* (pp. 207–221). New York: Nova Science.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, *81*, 141–145.