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Where cognitive development and aging meet: Face learning ability peaks after age 30 ☆

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ABSTRACT

Research on age-related cognitive change traditionally focuses on either development or aging, where development ends with adulthood and aging begins around 55 years. This approach ignores age-related changes during the 35 years in-between, implying that this period is uninformative. Here we investigated face recognition as an ability that may mature late relative to other abilities. Using data from over 60,000 participants, we traced the ability to learn new faces from pre-adolescence through middle age. In three separate experiments, we show that face learning ability improves until just after age 30 – even though other putatively related abilities (inverted face recognition and name recognition) stop showing age-related improvements years earlier. Our data provide the first behavioral evidence for late maturation of face processing and the dissociation of face recognition from other abilities over time demonstrates that studies on adult age development can provide insight into the organization and development of cognitive systems.

1. Introduction

In an American television advertisement for the video game "Brain Age", an older gentleman is greeted by an old friend whose face he does not recognize. Fortunately, with the help of video game technology, he begins to train his brain to function at its peak: a brain age of 20 years. Part of what makes this scenario credible is the pervasive idea both in popular culture and science that our cognitive faculties peak where development ends, and development ends with biological maturity (around age 20). In line with this notion, there is a large literature demonstrating that cognitive performance declines over most or all of adulthood (Li et al., 2004; Salthouse & Babcock, 1991). Cognitive measures that show increases or stability during adulthood (such as vocabulary) are typically associated with acquired knowledge (e.g. crystallized intelligence: Cattell, 1971). Only lately has brain development after childhood become a major focus of research (Blakemore & Choudhury, 2006; Giedd et al., 1999; Gogtay et al., 2004; Luna & Sweeney, 2001; Paus, 2005). Recent evidence indicates that the processes responsible for brain maturation and change – synaptic proliferation, synaptic pruning, and myelination – continue through adolescence and into adulthood (Sowell et al., 2003).

Face processing has enjoyed significant, if mixed, attention over the past 30 years as a late maturing ability. Research has suggested that the quantity and quality of face processing continues to increase throughout adolescence (Carey, Diamond, & Woods, 1980; Diamond, Carey, & Back, 1983; Lawrence et al., 2008) and that face recognition may reach adult levels only at a relatively late age of about 16 years (Grill-Spector, Golarai, & Gabrieli, 2008; Itier & Taylor, 2004). Early studies looking at face recognition development indicated that some core features of face processing do not emerge until around 10 years (Carey &

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Diamond, 1977; Carey et al., 1980). This conclusion has been challenged by subsequent theoretical and empirical work demonstrating that although face processing may improve during childhood, face processing is qualitatively similar in adults and children as young as 4 years old (see McKone, Crookes, & Kanwisher, 2009 for a review). Some researchers have argued that increases in face processing performance beyond childhood may be accounted for by differences in attention, concentration, and/or general memory rather than changes in face perception mechanisms (Crookes & McKone, 2009; Itier & Taylor, 2004; Lundy, Jackson, & Haaf, 2001; McKone & Boyer, 2006; Mondloch, Maurer, & Ahola, 2006). A recent study by Lawrence et al. (2008), however, found linear improvements in face recognition from 6 to 16 years even after effects of IQ were partialled out.

It is unclear from existing behavioral studies whether face processing undergoes extended development beyond what can be accounted for by the development of more generic processes. Results from functional neuroimaging experiments are more promising, however: to date, several functional neuroimaging experiments have documented consistent changes in face-selective brain responses with increasing age (Aylward et al., 2005; Golarai et al., 2007; Passarotti et al., 2003; Scherf, Behrmann, Humphreys, & Luna, 2007; Taylor, Batty, & Itier, 2004). Using fMRI, researchers noted expansion of the fusiform face area (FFA) from childhood to adulthood (Aylward et al., 2005; Golarai et al., 2007; Scherf et al., 2007). Critically, this expansion was evident even though face-selective areas of the superior temporal sulcus and object recognition areas such as lateral occipital complex did not change in extent (Golarai et al., 2007). Along similar lines, Scherf et al. (2007) found similar selectivity and extent of place and object selective areas in children, adolescents, and adults alongside changes in face selective regions. Furthermore, Golarai et al. (2007) found that the spatial extent of right FFA was correlated with face recognition memory in children and adolescents, but not object or place recognition memory. These functional data point to changes in face-specific processing that extend into late adolescence. Nevertheless, the absence of a clear behavioral effect attributable specifically to face processing over this age range makes these results difficult to interpret, leading McKone et al. (2009) to speculate that FFA size may be related to changes in selective top-down modulation and not to face processing ability per se. An alternative raised by McKone et al. (2009) that is also consistent with the finding of Golarai et al. (2007) is that changes in FFA size may be due to differences in long-term storage of face information, which may or may not be related to differences in face-specific abilities.

Finally, there is also convergent evidence that face recognition ability declines over later adulthood (Chaby, Jemel, George, Renault, & Fiori, 2001; Maylor & Valentine, 1992; Shapiro & Penrod, 1986) with reductions evident as early as 50 years of age (Crook & Larrabee, 1992). Furthermore, declines in face processing ability are associated with functional changes in the brain (Grady, McIntosh, Horwitz, & Rapoport, 2000) as well as changes in white matter connectivity of face processing regions (Thomas et al., 2008).

Here, we conducted a series of behavioral experiments to test the hypothesis that face recognition continues to improve beyond childhood and through adolescence. By investigating changes in face recognition ability beyond adolescence and into adulthood, we also were able to observe whether certain domains of memory and/or visual recognition develop beyond early adulthood. Using a large sample ($n \approx 44{,}000$) collected over the internet, we conducted a year-by-year analysis of face recognition ability in a cross-section of the population aged 10–70 years (Experiment 1). While we expected to see improvements over the course of adolescence, we were surprised by what we actually observed: steady increases in face learning ability through late adolescence with performance peaks after age 30.

All participants gave informed consent before participating and the protocol was approved by the Committee for the Use of Human Subjects at Harvard University.

2. Experiment 1: Cambridge Face Memory Test

2.1. Method

The Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006) is a test of unfamiliar face recognition that requires participants to learn and then recognize six target faces in conditions of varying difficulty. It has been used to detect subtle face recognition impairments in individuals with developmental prosopagnosia and has been shown to have good psychometric properties (Duchaine & Nakayama, 2006; Garrido, Duchaine, & Nakayama, 2008; Iaria, Bogod, Fox, & Barton, 2009; Wilmer et al., 2010).

We created an internet-based version of this test, using a new set of young, adult Caucasian male faces created with FaceGen software (Singular Inversions, Inc.). All faces were shown in grayscale with no visible hair or other distinguishing non-face features. In the first portion of the test, target faces were introduced to participants in three different views, with each face image presented for 3 s. After studying a face in each view, participants were presented with three forced-choice items. Each item included a study image of the target face and two nontarget faces shown in the same pose and lighting. The study and test cycle was repeated for six target faces, making a total of 18 items. After this introductory phase, participants were tested on 54 forced-choice items, each containing one target and two nontarget faces shown in novel views and under varied lighting conditions. Participants did not know on any given trial which of the six target faces would be present. In the last 24 trials, items were presented with visual noise added to make them more difficult. The final score for each participant was the total number of items correct out of 72 items (18 introductory items + 30 items with novel images + 24 with novel images and visual noise). An independent sample of 11 participants (6 female; age range: 21–35; mean age = 28, SD = 4) judged the average age of the target faces in this experiment as being 25.9 years of age (SD = 1.3). Sample images from the test are shown in Fig. 1.

2.2. Participants

Visitors came to our website to participate in internet-based tests of visual recognition memory. Visitors arrived primarily through links posted on other websites, including popular media, social networking sites, blogs, and other user-generated links. Tests were advertised on the main page of our website as either "Online Cambridge Face Memory Test" (Experiment 1) or "Test My Memory" (Experiments 2 and 3). Of the 51,403 participants who completed Experiment 1, 44,680 met our criteria for inclusion in the current sample. Participants were excluded if they answered no to the question "Is this your first time taking this test?", if they had the same email address as another participant (indicating repeat participation), if they did not enter a gender that was clearly classifiable as male or female, if their total number correct was 0 (indicating technical problems or errors writing to the database), or if they listed an age that was less than 10 years or greater than 70. Participants included in this dataset had a mean age of 27.8 years (SD = 12). A summary of participant numbers at different ages, including participants of each sex, is provided in Fig. 2. Approximately 61% of participants were female. All tests are available at our website at http://www.testmybrain.org/visualmemory.php.

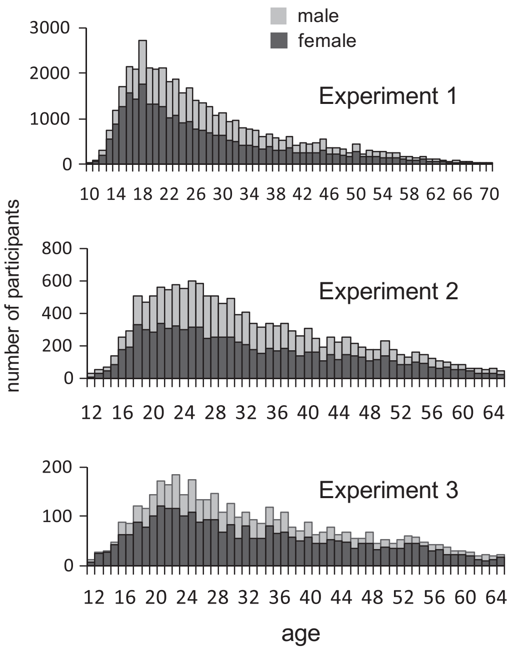

Fig. 2. Number and sex of participants at each age. The height of each bar represents the total number of participants at each year of age. Number of females per year of age is shown in dark gray with number of males shown in light gray. The smallest age bins were at age 70 for Experiment 1 ($n = 26$), age 12 for Experiment 2 ($n = 33$), and age 12 for Experiment 3 ($n = 12$).

2.3. Results

We found that the age of peak performance was significantly higher than we would have expected based on

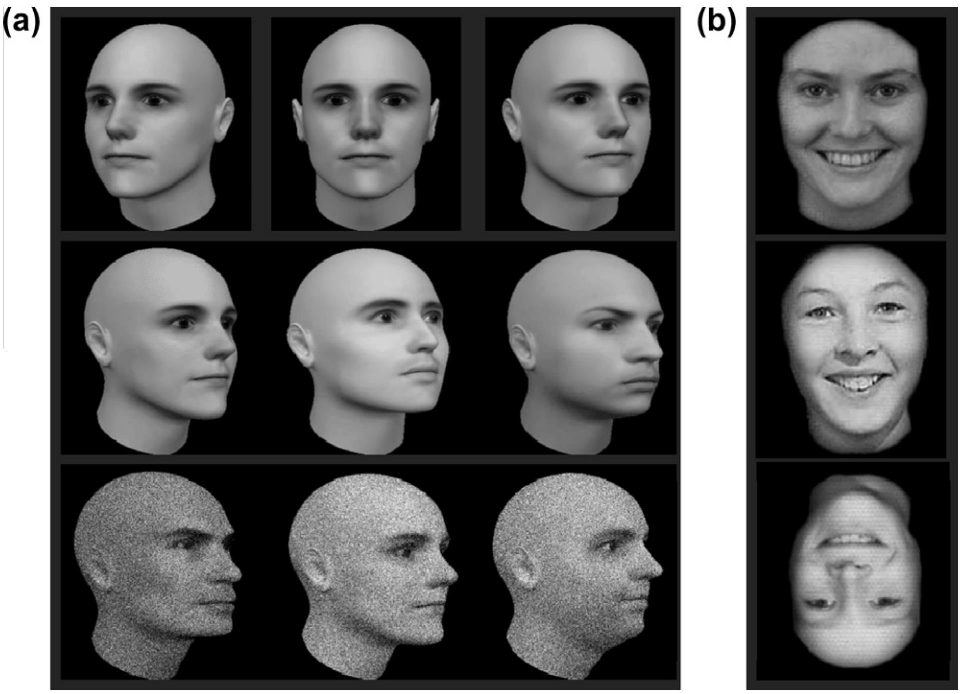

Fig. 1. Face images from Experiments 1 and 3. (a) Stimuli from Cambridge Face Memory Test (v.2; Experiment 1) including study images (top), a test item with novel target image (middle), and a test item with a novel target image and noise (bottom). (b) Stimuli from Experiment 3: upright adult face (top), upright child face (middle), and inverted child face (bottom).

previous literature. Fig. 3a shows proportion correct on the CFMT, averaged by the age of our participants. Across all ages, mean proportion correct on this task was 0.81 and the average standard deviation of scores at each age bin was 0.13 (standard deviation of standard deviations across age bins, SD of SD = 0.01). Consistent with previous studies, face recognition increases steeply from the ages of 10 until approximately 20 years. At that point the slope reduces, but remains positive until just after age 30. Performance at 16 is comparable to performance at 65. The suggestion in the data of a pause in development from age 12 to 13 is consistent with studies by Carey et al. (1980) and by Flin (1980), reporting a dip or plateau in face recognition performance at the onset of puberty.

Effect sizes for performance on the CFMT across the interval 12–20, 20–30, and 30–65 are shown in Table 1. These effect sizes indicate large improvements in performance from adolescence through adulthood and significant age-related decline from 30 to 65 years.

To more precisely determine the age at which performance is best, we required a method to estimate the peak of the age function shown in Fig. 3a as well as a standard error for this value. The age function we observed closely approximated an inverted parabola when the scores were plotted linearly and age was plotted logarithmically (See Fig. 3b), and so we fitted the data to a quadratic function. To generate an estimate of the standard error, we used a bootstrap resampling procedure, resampling 200 times (Efron & Tibshirani, 1993). In this procedure, we replaced age with log(age) and sampled (with replacement) from the data (N = 44,680). This resampling procedure was repeated 200 times. For each new sample, we found the maximum of the best-fit quadratic function to give 200 values. We took the mean and standard deviation of these values as our estimate of the age peak and the standard error of that estimate, respectively. Fig. 3c shows that this age peak is indeed much higher than expected (approximately 31.4 years) with a standard error of about half a year. The same peak (31.4 years) was observed for both male and female participants when analyzed separately.

3. Experiment 2: old/new faces and names

Studies of face recognition development have been criticized for assuming that differences in face recognition at different ages reflect changes in face-specific abilities rather than more generic memory or performance differences (McKone et al., 2009). Based on the data from Experiment 1 alone, we cannot conclude that our performance curve reflects genuine differences in face recognition rather than differences in other general factors affecting performance that vary with age. Along similar lines, we wanted to be certain that our results were not being driven by performance-related factors arising from self-selection biases in our sample. It might be the case that participants at different age groups came to the website for different reasons that might impact performance. For example, participants in their early 20s may have navigated to our website for entertainment purposes whereas participants in their early 30s had an interest in challenging themselves and testing their abilities and thus would be more motivated. Finally, we wanted to confirm that our effect was replicable using a different face testing procedure.

3.1. Method

We addressed these issues in Experiment 2 by running a pair of measures to look at recognition memory for unfamiliar faces and for unfamiliar names. Our face recognition measure was an old/new recognition memory test that required participants to learn the faces of 10 unfamiliar female targets (Duchaine & Nakayama, 2005, 2006; Duchaine, Yovel, Butterworth, & Nakayama, 2006a and 2006b; Harris, Duchaine, & Nakayama, 2005; Steeves et al., 2006).

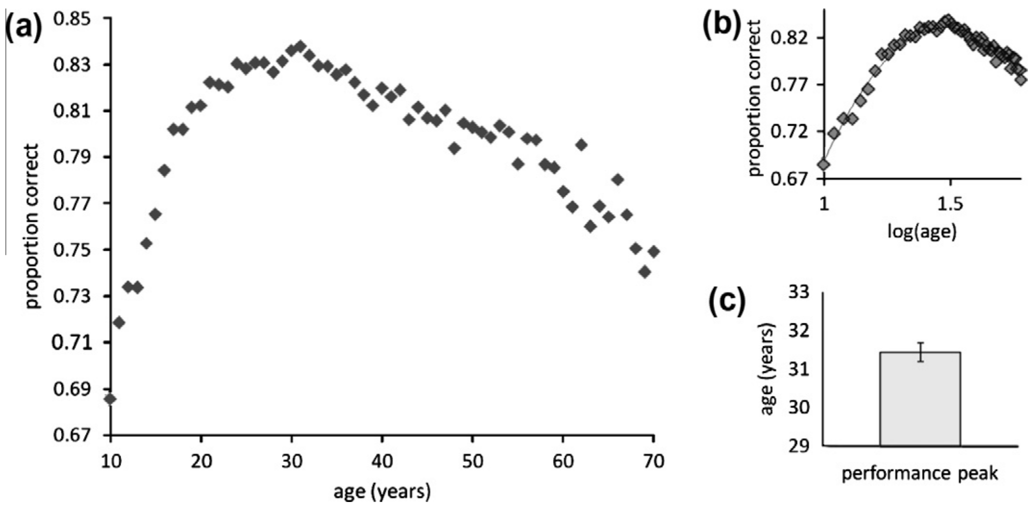

Fig. 3. Peak estimation – Cambridge Face Memory Test (v.2). (a) Performance on the Cambridge Face Memory Test in terms of percent correct, averaged by age of participants. (b) A log transformed bootstrapped sample, averaged by age. Peak performance for each bootstrapped sample was estimated by finding the peak of the best-fit quadratic function to the transformed sample. (c) Mean and standard error of age of peak performance based on bootstrap resampling and curve-fit analysis.

Table 1
Effect sizes across different age ranges for each task (Exp 1–3). Effect sizes across three age intervals are presented in three ways for Experiments 1–3. Bivariate correlation coefficients between age and recognition memory performance are shown for data binned by year of age [*r* (binned)] and data without binning [*r* (unbinned)]. Cohen's *d* is shown for the difference between means across the age ranges. Cohen's *d* gives the number of standard deviations difference between two groups, and was calculated using the formula: $d = (X_2 - X_1)/((s_1^2 + s_2^2/2)^{1/2}$. X_1 and S_1 are the mean and standard deviation of the first age group, whereas X_2 and S_2 are the mean and standard deviation of the second age group. For Experiments 2 and 3, where more than one test was administered to each participant, *Z* scores are given for the differences between age-performance correlations for different tests in each age range.

Age range	*r* (binned)	*r* (unbinned)	Cohen's *d*
Exp l: Cambridge Face Memory Test (CFMT)			
Age and CFMT performance			
12–20	0.98**	0.2**	0.61
20–30	0.89**	0.06**	0.21
30–65	−0.92**	−0.12**	−0.62
Exp 2: Old/new faces and names			
Age and old/new faces performance			
12–20	0.85*	0.14**	0.47
20–30	0.91**	0.07**	0.18
30–65	−0.88**	−0.11**	−0.53
Age and old/new names performance			
12–20	0.60†	0.007	0.16
20–30	−0.41	−0.01	−0.11
30–65	−0.80**	−0.08**	−0.32
Difference between correlations: faces vs. names			
Age range	Zl (from binned correlations)	Zl (from unbinned correlations)	
12–20	1.0	4.8**	
20–30	2.3*	3.6**	
30–65	0.73	−2.3**	
Exp 3: Old/new upright and inverted faces			
Age and upright faces (average) performance			
12–20	0.55	0.12*	0.31
20–30	0.52	0.05^	0.22
30–65	−0.75**	−0.14**	−0.78
Age and inverted faces performance			
12–20	0.66†	0.07†	0.23
20–30	−0.38	−0.03	−0.05
30–65	−0.79**	−0.15**	−0.77
Difference between correlations: upright vs. inverted			
Age range	Zl (from binned correlations)	Zl (from unbinned correlations)	
12–20	−0.33	1.2	
20–30	2.4*	3.2**	
30–65	0.36	0.49	

* $p < 0.01$.
** $p < 0.001$.
^ $p < 0.05$.
† $p < 0.1$ (trend).

All faces were shown in grayscale and cropped, with no visible hair or other identifying non-face features. All faces were from individuals of Caucasian descent and an independent sample of 11 participants (see Experiment 1) judged the average age of the target faces as 25.8 years of age (SD = 0.99). In the learning phase, target faces were presented for 3 s each, two times per face. In the test phase, participants were presented with a face and asked to indicate if the face was one of the target faces (old) or a face that they had not seen before (new). Each target face appeared twice during the test phase, with 30 additional nontarget faces presented once each. Performance in this test was calculated as proportion correct out of 50.

The Name recognition test was adapted from the Doors & People Test of verbal recognition memory (Baddeley, Emslie, & Nimmo-Smith, 1994) and required participants to learn 12 unfamiliar male names. In the learning phase of this test, target names were presented on screen for 3 s each. In the test phase, participants were presented with a list of four names and were asked to indicate the target name. Distractor names always had the same first name as the target name, with last names that were chosen to be highly similar (e.g. Brownfield, Brownstone, Brownley, Browning). Performance in this test was percent correct out of 12.

Test order was counterbalanced across participants. We used the same bootstrap resampling and curve fitting procedure as in Experiment 1 to estimate a mean and standard error for the peak of each recognition curve.

3.2. Results

Results were calculated based on the 14,822 out of 18,552 participants who completed both tests. Criteria for inclusion were the same as in Experiment 1, except that the age range was limited to 12–65 due to low participant numbers in the youngest and oldest ages examined in Experiment 1. Experiment 2 was available on our site at a different time than Experiment 1, so overlap between experiments is unlikely to be significant. The mean age of participants was 33.8 (SD = 12.4). Fifty-seven percent of participants were female. Across all ages, mean proportion correct on the names task was 0.74 and the average standard deviation of scores at each age bin was 0.17 (standard deviation of standard deviations across age bins, SD of SD = 0.01). Mean proportion correct on the old/new faces task was 0.84 and the average standard deviation of scores at each age bin was 0.1 (SD of SD = 0.01). Number of female and male participants at each year of age is shown in Fig. 2.

For the unfamiliar faces test, the mean peak in performance was at 33.1 years (see Fig. 4). This peak was similar for male (31.5, SE = 0.5) and female participants (32.2, SE = 0.6). For the same set of subjects, the mean peak in performance on the unfamiliar names test was 23 years. Again, males and females showed comparable peaks (males: 23.1, SE = 3.6; females: 22.4, SE = 2.3). Hence, we were able to replicate our initial result and further confirm that the observed late peak in face recognition cannot be explained by changes in general factors affecting attention, memory, motivation or sampling irregularities related to self-selection. Effect sizes for the old/new faces and old/new names tests are shown in Table 1. Over the interval from 20 to 30 years old, it is noteworthy that recognition memory for faces improves even as recognition memory for names stays relatively stable (see Table 1). Based on Steiger's Z1* statistic for comparing correlations from the same sample (Steiger, 1980), age-related changes in recognition memory for faces and for names significantly differed over this interval (see Table 1).

4. Experiment 3: old/new adult faces, child faces, and inverted child faces

Since the face images in Experiments 1 and 2 were limited to the faces of adults, it was conceivable that the late age peak might reflect a systematic age-related advantage for learning certain age faces (Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008). Perhaps younger participants would be better at learning younger faces? In addition, it was still unclear whether the performance curve we were observing reflected face recognition memory or simply more general differences in visual pattern-encoding ability or visual memory.

4.1. Method

In Experiment 3, we sought to address these concerns by testing two additional types of stimuli. In addition to testing recognition of upright adult faces, we also tested recognition of upright child faces to see if performance peaks were related to the age of to-be-learned faces. Finally, a third test was administered using unfamiliar inverted child faces, to see whether peak performance was related to general pattern encoding or visual recognition memory.

All three tests followed a similar format to the old/new face recognition test in Experiment 2, but with different face images. Child faces were photographs of individuals

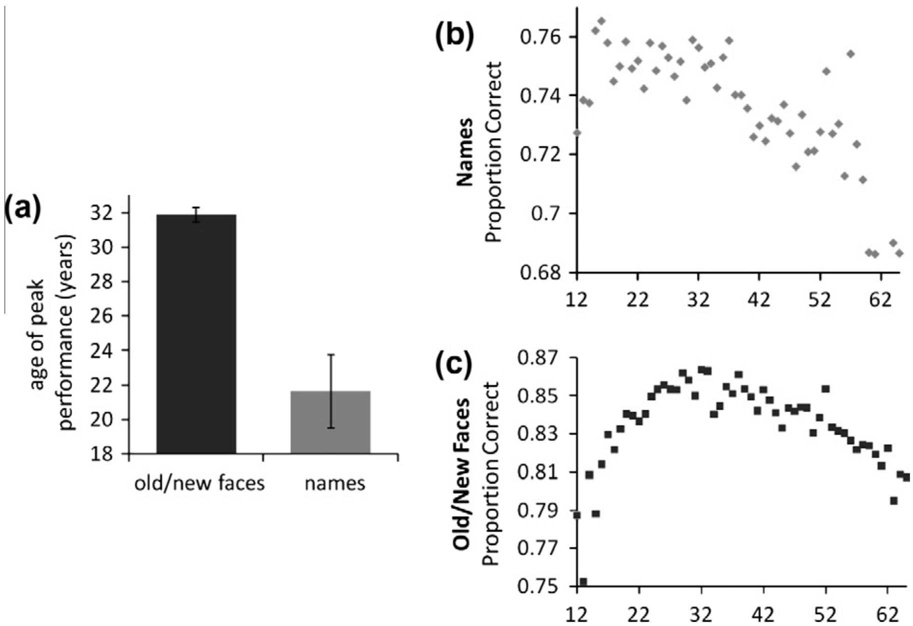

Fig. 4. Ages of peak performance in old/new faces and names tests (Experiment 2). (a) Mean and standard error for age of peak performance based on bootstrap resampling and curve-fitting of recognition memory performance across the lifespan for unfamiliar faces and names (Experiment 2). Error bars show ± one standard error. (b) Performance on the name recognition test in terms of proportion correct, averaged by age of participants. (c) Proportion correct on the old/new faces test, averaged by age of participants.

between 6 and 10 years of age. Both adult and child faces were of Caucasian descent, and an independent sample of 11 participants (see Experiment 1) judged the average age of the faces as being 25.4 years of age (adults faces; SD = 1.5) and 11.7 years of age (child faces; SD = 0.53). In each of the three tests, participants were required to learn the faces of 10 unfamiliar female targets (10 upright child faces, 10 upright adult faces, and 10 inverted child faces). In the learning phase, target faces were presented for 3 s each, once per face. In the test phase, participants were presented with a face and asked to indicate if the face was one of the target faces (old) or a face that they had not seen before (new). Faces were shown in the same orientation for both learning and test phases. Each target face appeared once during the test phase, with 20 additional nontarget faces presented once each. Performance in each test was calculated as proportion correct out of 30.

Test order was counterbalanced across participants. The mean and standard error of the peak of each recognition curve was estimated using the same procedure as in Experiments 1 and 2.

Based on previous reports of age-related changes in recognition performance for inverted as compared with upright faces (Carey et al., 1980), we also looked at the performance cost of face inversion at different ages. For each participant, we subtracted inverted face recognition scores from average upright face recognition scores and looked at face inversion effects as a function of age.

4.2. Results

Our final sample size was based on 4280 out of 6474 participants who completed all three tests. Inclusion criteria were the same as in Experiment 2. Experiment 3 was available on our website at a different time than Experiments 1 and 2. The mean age of these participants was 33.2 years (SD = 13), with 69% females. Across all ages, mean proportion correct on the upright adult faces task was 0.88 and the average standard deviation of scores in each age bin was 0.09 (standard deviation of standard deviations across age bins, SD of SD = 0.01). Mean proportion correct on the upright child faces was 0.86 and the average standard deviation of scores at each age bin was 0.1 (SD of SD = 0.01). Mean proportion correct on the inverted child faces was 0.67 and the average standard deviation of scores at each age bin was 0.11 (SD of SD = 0.01). The number of male and female participants in each age bin is shown in Fig. 2.

Fig. 5a shows that memory performance for upright faces peaked at 31.6 years for adult faces (male participants: 31.0, SE = 1.5; female participants: 31.2, SE = 1.3) and 30.1 years for child faces (male participants: 31.4, SE = 1.3; female participants: 30, SE = 1.7). In the same sample of subjects, recognition of inverted faces was at its maximum in participants aged 23.5 years (male participants: 26.9, SE = 1.9; female participants: 21.8, SE = 2.3). Males had a significantly later peak for inverted face recognition memory than females ($p < 0.001$), but earlier than their peak for upright faces ($p < 0.001$).

Effect sizes for differences in upright and inverted face recognition performance across three age ranges are shown in Table 1. Again, we observed specific increases in upright face recognition performance over the interval from age 20 to 30, accompanied by decreases or relative stability in inverted face recognition memory. Moreover, we also observed an increasing cost of face inversion on

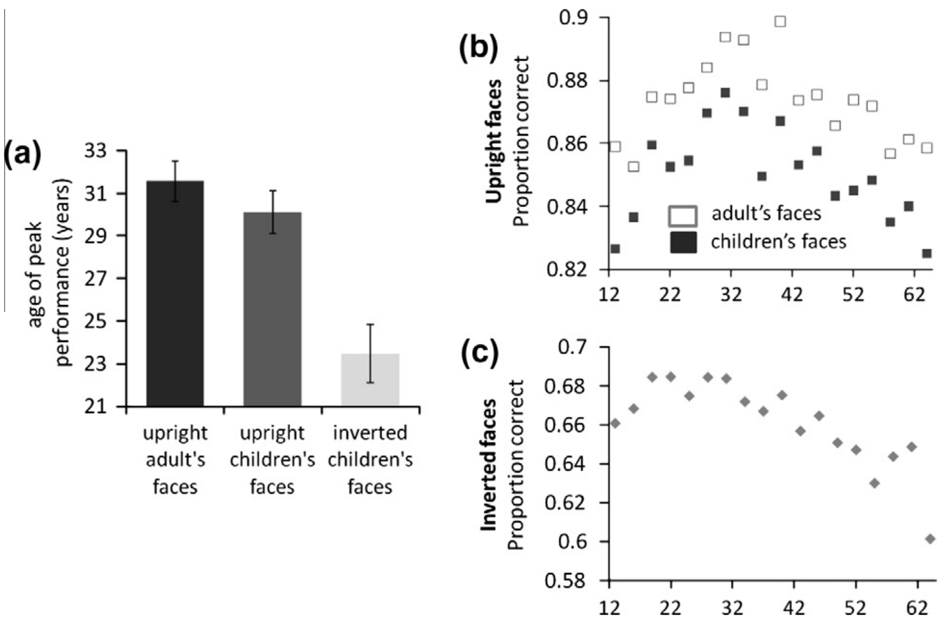

Fig. 5. Ages of peak performance for recognition of upright and inverted faces of different ages (Experiment 3). (a) Mean and standard error for age of peak performance based on bootstrap resampling and curve-fitting of recognition memory performance across the lifespan for upright adult faces, upright child faces, and inverted child faces (Experiment 3). Error bars show ± one standard error. (b) Performance on the upright adult and upright child faces tests in terms of proportion correct, averaged by age of participants. (c) Proportion correct on the inverted faces test, averaged by age of participants.

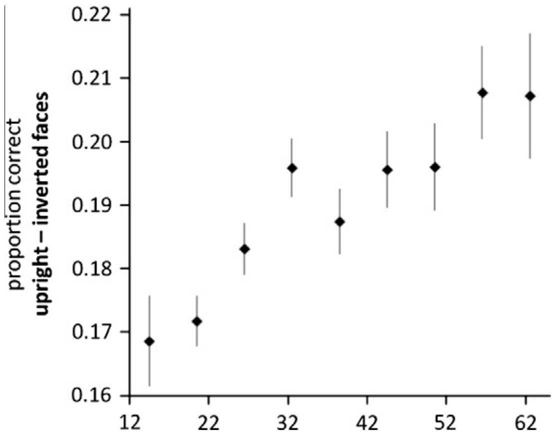

Fig. 6. Increases in the cost of face inversion on recognition performance with age. Shown are differences in proportion correct for upright (average performance with adult and child faces) versus inverted faces, averaged across 6 year age intervals from 12 to 65 years old. Bars show standard error for each interval. For comparison, average performance at each year of age for upright and inverted face recognition are shown separately in Fig. 5.

recognition memory across the entire age range (average upright score – inverted face score; binned by year of age: $r = 0.61$, $p < 0.05$; unbinned: $r = 0.11$, $p < 0.0001$; see Fig. 6). This relationship further illustrates differences in the developmental trajectories underlying recognition of these two types of stimuli.

5. Discussion

In a series of experiments, we report the novel finding that the ability to learn and recognize unfamiliar faces improves until the early 30s. We found this result four times, with two different testing procedures and four sets of face stimuli. We also found that ages of peak recognition memory for faces (30–34 years) differed from the ages of peak recognition memory for names and inverted faces (23–24 years). Increases in face recognition from 20 to 30 years were accompanied by stability/decline in name and inverted face recognition in the same set of participants. The dissociation we found between face and name recognition memory confirms that improvements in face learning ability cannot be explained by differences in general factors related to performance, memory, or participant self-selection. The dissociation between upright and inverted face recognition memory further demonstrates that extended improvements for upright faces were not due to improvements in general factors related to general visual recognition memory or pattern encoding. Altogether, our results indicate that developmentally interesting changes take place during early to middle adulthood – in the window between development and aging – and that these changes can inform us about the basic organization and development of cognitive systems. Our results from Experiments 2 and 3 show that face recognition memory relies on mechanisms that develop differently from those responsible for some other types of recognition memory.

In Experiment 3, we observed an inversion effect that increased with age (Fig. 6). We interpret this increasing inversion effect in our dataset as being due to extended improvements in upright face recognition ability relative to inverted face recognition in early adulthood. The dissociation between upright and inverted face recognition suggests that developmental patterns for upright face recognition memory in our sample are at least somewhat specific to upright faces. A face-specific account would be consistent with findings from functional neuroimaging of age-related changes in activation of face-specific areas of ventral temporal cortex and not of other nearby regions (Golarai et al., 2007; Scherf et al., 2007). Notably, these face-specific regions have been shown to be preferentially involved in processing upright faces (Yovel & Kanwisher, 2005).

How do we interpret our findings and what do they suggest about cognitive development? One possibility is that these changes are endogenously driven and/or reflect biologically programmed maturational processes. If this were the case, it is likely we would see the same trends and ages of peak performance across widely sampled populations, regardless of visual experience. Alternatively, our findings may reflect the impact of extended experience with a particular stimulus class (e.g. upright faces). Face recognition memory may continue to improve beyond the point that pattern encoding or other forms of visual recognition memory have finished developing because face recognition is used on a daily basis and reflects a highly practiced skill. If we sampled a cross-section of bird aficionados at different ages, for example, we would not expect their bird recognition memory to peak at the same time as their visual recognition memory, more generally. Instead, we might predict that their ability to recognize familiar birds would show extended improvement with increasing expertise. Extended development is exactly what we found with upright face recognition memory (relative to another visual stimulus class). Essentially, daily life may provide training for upright face recognition (but not inverted face recognition) that fine-tunes face memory in early adulthood.

Although we addressed the possibility of an own age bias by using children's faces in Experiment 3, it is possible that a comparable age peak was driven by the fact that individuals in this same age group (early 30s) are also most likely to have children of a similar age to the ones used in our experiment. If more of the 30 year olds have children aged 6–10 years then other age groups, this may have accounted for peak recognition of this stimulus group at that age. It is also possible that our effect is driven by the interaction between participant race/ethnicity and the race of the target faces used. Previous research has demonstrated a robust other race effect in face recognition, where people find the faces of other race individuals more difficult to recognize (Meissner & Brigham, 2001). All of our stimuli were Caucasian faces, so if participants in their early 30s included the highest proportion of Caucasians, this could also account for the effects that we observed. We did not collect data on participant race/ethnicity or whether participants had children, so we cannot exclude either of these possibilities.

The current experiments relied on data gathered entirely from web-based tests. Current research indicates that data collected from the web can be highly reliable, empirically valid (Birnbaum, 2004, Gosling, Vazire, Srivastava, & John, 2004, Haworth et al., 2007, Kraut et al., 2004, McGraw, Tew, & Williams, 2000, Wilmer et al., 2010), and of broad theoretical interest (Owen et al., 2010; Wilmer et al., 2010). Still, it was not possible to ascertain and control for biases in self-selection in the current samples or to verify the accuracy of the information provided by participants. For example, it is likely that our sample was more interested in face recognition, memory, or cognitive ability than the average person recruited in a lab setting. Data we have collected on other, similar tests of memory (including the standard version of the Cambridge Face Memory Test) indicate that performance and reliability are comparable for internet-based and traditional lab-based samples (Wilmer et al., 2010). Internet testing ultimately allowed us to collect data from a very large and diverse sample that would not have been practically feasible in a traditional lab setting.

One major limitation of the current study is our reliance on cross-sectional data. Although we have interpreted our findings as reflective of underlying developmental and aging processes, we cannot conclude with certainty that our findings are due to developmental changes as opposed to cohort effects (Schaie, 1965). A longitudinal investigation of face learning ability over time would be needed to exclude this possibility.

Although effect sizes over the range 12–20 years were of reasonable size and equivalent to aging effects in our sample (cohen's $d = 0.61$; see Table 1), effect sizes over the 20–30 years age range were small (cohen's $d = 0.21$). Thus, it remains to be seen whether gains over the interval from 20 to 30 years of age are related to differences in everyday face recognition in the real world.

In these experiments, we did year-by-year sampling of a much larger age range than has previously been reported in studies of visual processing or recognition memory. This allowed us to look at face recognition memory at every age from early adolescence through late adulthood, and provided a window through which we observed developmental increases, age-related decline, and the point at which these two processes intersect. Studies employing behavioral methods frequently focus on either development or aging, with relatively arbitrary and truncated cut-offs for either process. This procedure means that informative and theoretically interesting variations that occur between the end of adolescence and late middle-age are inevitably obscured. Our data illustrate that meaningful changes can and do occur during early and middle adulthood and suggest a need for integration of research in cognitive development and aging.

Finally, our results have important implications for any research involving between-group measurements of cognitive abilities using college age or young adult populations. We typically assume that most cognitive abilities are stable over this age range typically included in undergraduate or college psychology participant pools. However, our data indicate that face recognition memory increases significantly during early adulthood, so that small differences in age could account for modest between-group differences. Although the current experiments focused on face recognition memory, it is possible that many other perceptual, mnemonic, and cognitive abilities may also show significant changes over this age range. Our results highlight the critical importance of accounting for age-related performance differences even in college-based or young adult populations.

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