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Developmental improvement and age-related decline in unfamiliar face matching

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Abstract. Age-related changes have been documented widely in studies of face recognition and eyewitness identification. However, it is not clear whether these changes arise from general developmental differences in memory or occur specifically during the perceptual processing of faces. We report two experiments to track such perceptual changes using a 1-in-10 (experiment 1) and 1-in-1 (experiment 2) matching task for unfamiliar faces. Both experiments showed improvements in face matching during childhood and adult-like accuracy levels by adolescence. In addition, face-matching performance declined in adults of the age of 65 years. These findings indicate that developmental improvements and aging-related differences in face processing arise from changes in the perceptual encoding of faces. A clear face inversion effect was also present in all age groups. This indicates that those age-related changes in face matching reflect a quantitative effect, whereby typical face processes are engaged but do not operate at the best-possible level. These data suggest that part of the problem of eyewitness identification in children and elderly persons might reflect impairments in the perceptual processing of unfamiliar faces.

Keywords: face matching, development, aging, individual differences

1 Introduction

Cognition improves with development and declines with aging. This fact is reflected clearly in different memory processes. Working memory capacity and long-term memory performance, for example, improve during childhood and adolescence but then worsen severely during old age (for extensive reviews see, eg, Graf & Ohta, 2002; Whitbourne & Sliwinski, 2012). The experiments reported here focus on an important aspect of human social cognition that may have been conflated with such age-related cognitive differences in memory—namely, the ability to process faces. Age-related changes in face recognition have already been documented extensively (for a review see, eg, Chung & Thomson, 1995). However, the majority of these studies have used memory-based tasks. It is now clear that performance in face identification is also a perceptual skill that is dissociable from face memory processes (see, eg, Burton, White, & McNeill, 2010; Megreya & Burton, 2008; Megreya, White, & Burton, 2011). As a consequence, it remains unresolved whether age-related changes in face recognition ability are due to developmental differences that reflect the memory component of previous tasks or whether these changes occur also during the perceptual processing of faces.

A substantial body of work shows that face recognition accuracy improves dramatically prior to adulthood. This finding is so robust that it has been replicated with a wide variety of recognition memory tasks (see, eg, Carey, Diamond, & Woods, 1980; Ellis & Flin, 1990; Mondloch, Geldart, Maurer, & Le Grand, 2003; Pezdek, Blandon-Gitlin, & Moore, 2003; Schwarzer, 2000) and eyewitness identification paradigms (Beal, Schmitt, & Dekle, 1995; Havard, Memon, Clifford, & Gabbert, 2010; Lindsay, Pozzulo, Craig, Lee, & Corber, 1997; Pozzulo & Balfour, 2006). However, these studies have reported mixed results regarding the nature of this improvement. Recognition memory experiments have found age-related improvements up until the age of 10 years in the correct identification of previously seen faces and also in the rejection of previously unseen faces (for reviews and meta-analysis see, eg, Chance & Goldstein, 1984; Chung & Thomson, 1995; Shapiro & Penrod, 1986).

However, eyewitness identification studies show that children over 5 years of age already produce a rate of correct person identifications that is comparable with adults (for a meta-analysis see, eg, Pozzulo & Lindsay, 1998) but older children continue to improve in making correct rejections (for a recent review see Havard, 2014).

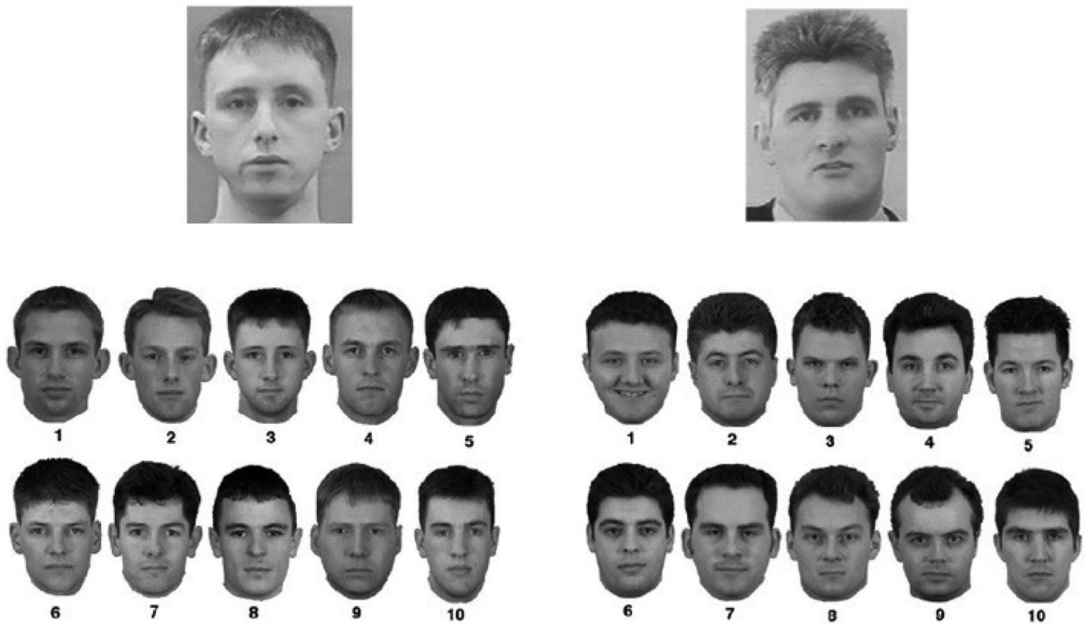
This contrast has been attributed to a key difference between face recognition and eyewitness identification tasks (Pozzulo & Lindsay, 1998). While the former typically require observers to encode and remember the faces of many individuals, the latter usually involve only a single target identity. The delayed onset of adult-like rates of correct identifications in face recognition experiments might therefore reflect the increased demands of these tasks. This points to an increase in memory load capacity with age rather than an improvement in face identification ability per se (Pozzulo & Lindsay, 1998).

In addition to improvements in face recognition memory during development, several studies have also shown that this ability deteriorates severely with aging. Once again, this effect has been demonstrated using tests of face memory (Bäckman, 1991; Bartlett, Shastri, Abdi, & Neville-Smith, 2009; Bartlett, Strater, & Fulton, 1991; Boutet & Faubert, 2006; Germine, Duchaine, & Nakayama, 2011; Lamont, Stewart-Williams, & Podd, 2005) and eyewitness identification (Memon, Bartlett, Rose, & Gray, 2003; Searcy, Bartlett, & Memon, 1999; Searcy, Bartlett, Memon, & Swanson, 2001). A similar age-related decline has also been observed with sequential identification tasks, in which memory loads are reduced through immediate stimulus repetitions (Habak, Wilkinson, & Wilson, 2008). These detrimental aging effects are manifested in the false acceptance of new faces as someone that was seen previously rather than a reduction in the correct recognition of such previously seen targets (eg, for reviews see Bartlett, 1993; Bartlett & Memon, 2006; Searcy et al., 1999).

Several theories have been proposed that aim to integrate the developmental and aging aspects of face recognition performance. On the one hand, children's face recognition immaturity has been linked to their inability to process configural information, whereby faces cannot be perceived as integrated holistic percepts of separate visual facial features (eg, the eyes, nose, and mouth) in the way that adults do (see, eg, Freire & Lee, 2001; Mondloch et al., 2003; Mondloch, Le Grand, & Maurer, 2002). On the other hand, aging-related increases in false identifications are thought to reflect deficits in recollecting context and an increased reliance on a *sense* of familiarity, rather than explicit conscious memories for a face, in making identification decisions (see, eg, Searcy et al., 1999). In support of this reasoning, a positive association has been found in older adults between only familiarity ratings for unfamiliar faces and the correct and incorrect identification rates for these stimuli as 'known' (see, eg, Bartlett & Fulton, 1991; Edmonds, Glisky, Bartlett, & Rapcsak, 2012; Rhodes, Castel, & Jacoby, 2008).

An important question for the interpretation of these age-related effects is whether these differences arise during the memorial or perceptual processing of faces. A few studies have already examined this question using the Benton Face Recognition Test (BFRT) (see Benton, 1980; Carey et al., 1980; de Heering, Rossion, & Maurer, 2012; Searcy et al., 1999). This neuropsychological test requires observers to match a face target to a six-person lineup, which contains either an identical image of the target (BFRT part 1) or three different images of the same target, which vary in viewpoint and lighting (BFRT part 2). In a pioneering study Carey et al. (1980) reported continuous developmental improvements on this test from 68% to 84% accuracy with eight groups of children and adolescents, which were aged between 7 and 16 years. In a more recent study de Heering et al. (2012) presented a computerized version of the BFRT to middle- and late-aged children (~7–10 years of age), early adolescents (~10–12 years of age), and young adults (19 years of age). de Heering et al. (2012) also reported reliable improvements between middle and late childhood, and between early adolescence and adulthood, but not between late childhood and early adolescence. In addition, some studies on aging also show that older adults (~70 years of age) score poorer than young adults (~24 years of age) on the BFRT (Benton, Eslinger, & Damasio, 1981; Searcy et al., 1999).

While these findings are informative, the effects of development (de Heering et al., 2012) and aging (Searcy et al., 1999) have not been compared directly with the BFRT. However, the BFRT also might not be best suited to capture age-related changes in perceptual processing of faces. Previous research in face recognition and eyewitness identification has shown inflated rates of false positives for children and older adults (eg, for reviews see Bartlett & Memon, 2006; Chung & Thomson, 1995; Havard, 2014; Pozzulo & Lindsay, 1998). The BFRT does not include target-absent trials, in which the targets are not present in the corresponding identity lineups, and that are crucial for measuring false positives. An alternative assessment that can capture such identification errors is the 1-in-10 task (Bruce et al., 1999). In this task observers are presented with target faces, which have to be selected from corresponding ten-face identity lineups (for an example see figure 1). Crucially, the target can be present or absent from the identity lineups, thus allowing for the measurement of correct identifications in the presence of the target and of false positives in its absence.



(a) (b)

Figure 1. Examples of Bruce et al.'s (1999) 1-in-10 face matching arrays. The person shown at the top may or may not be one of the ten below. Observers have to decide whether this target is present, and if so, which lineup face he is. The target is lineup face 3 in (a) and is not present in (b).

This task is considered a best-case scenario for measuring face perception as all images are matched for viewing angle, lighting and pose, and the targets, and their counterparts in the lineup were photographed only a few minutes apart. Despite this, performance on the 1-in-10 task is surprisingly poor (Bruce et al., 1999). When the target is present in a lineup, it is identified correctly on only approximately 70% of trials. Similarly, the targets' absence from the lineups is noted about 70% of the time while false identifications of other lineup members occur on 30% of trials.

This low level of performance has now been replicated many times (Konar, Bennett, & Sekuler, 2010; Megreya & Bindemann, 2013; Megreya & Burton, 2006a, 2007, 2008; Megreya et al., 2011). In most of these studies the targets are presented immediately prior to the identity lineups. Crucially, however, the same performance pattern also holds when memory demands are eliminated by presenting the photographs of target faces simultaneously with the corresponding lineups (Bindemann, Sandford, Gillatt, Avetisyan, & Megreya, 2012; Megreya & Burton, 2006b) and even when live targets are shown alongside the lineup displays (Megreya & Burton, 2008). This indicates that the 1-in-10 task provides a good test of face perception for conditions in which the influence of memory factors should be minimized.

The 1-in-10 task also appears to be a good index of an individual's face identification ability. For example, performance in this task can be used to estimate the identification accuracy of individual eyewitnesses (eg, Bindemann, Brown, Koyas, & Russ, 2012) and correlates with aspects of personality, such as anxiety (Megreya & Bindemann, 2013). This sensitivity to individual differences suggests that the 1-in-10 task is also an appropriate test for studying different age groups. The present study therefore sought to assess age differences in face identification with the 1-in-10 task. We compared seven different age groups—comprising young children; adolescents; and young, middle-aged, and older adults—to chart both the development and decline of facial identification.

2 Experiment 1

This experiment examined age differences in face perception using the 1-in-10 matching task for unfamiliar faces (see Bruce et al., 1999). In each trial of this task observers were shown a target face and a concurrent lineup of ten faces, in which the target could be present or absent. Observers had to decide whether the target is present, and if so, indicate who it is. This matching task provides a useful test of individual differences (see, eg, Bindemann et al., 2012; Megreya & Bindemann, 2013; Megreya & Burton, 2006b). In contrast to previous studies on age differences in facial identification, this matching task also minimizes memory demands (cf, eg, Bäckman, 1991; Bartlett et al., 1991; Germine et al., 2011; Lamont et al., 2005) and allows for the measurement of false positives (Benton et al., 1981; Carey et al., 1980; de Heering et al., 2012; Searcy et al., 1999). Experiment 1 compared seven age groups with this task, ranging from 7 to 65 years of age.

2.1 *Method*

2.1.1 *Participants.* A total of 330 Egyptian participants volunteered for this experiment. These consisted of children; adolescents; and young, middle-aged, and older adults. The children and adolescents were recruited from primary and secondary schools in Menoufia, Egypt, whereas young adults were recruited from Menoufia University. Parental consent for participation for child and adolescent participants was obtained prior to the experiment. The middle-aged adults were teachers at the primary and secondary schools where all children were recruited or were employees at Menoufia University. The oldest age group consisted of retired adults. These participants were assigned to seven groups, with mean ages ranging from 7 to 65 years. Details of these age groups are provided in table 1. All participants had normal or corrected-to-normal vision and self-reported to be in good health.

Table 1. Summary statistics for the seven age groups of the participant sample in experiment 1.

Age group/years	*N*	Sex		Age (SD)
		male	female	
7	40	20	20	7.3 (0.5)
10	50	25	25	10.0 (0.7)
13	40	20	20	13.4 (0.5)
16	50	25	25	16.1 (0.2)
19	50	17	33	19.5 (1.5)
35	50	20	30	34.9 (2.8)
65	50	32	18	65.0 (4.7)

2.1.2 *Stimuli.* The stimuli consisted of 50 target-present and 50 target-absent face-matching arrays (see figure 2). These arrays were taken from an Egyptian database (see Megreya & Burton, 2008), which was constructed from facial photographs of university students. Each of these arrays consisted of a still image of an unfamiliar face target, which was recorded with a video camera. In each stimulus display an identity lineup was shown below this target image. This consisted of photographs of ten faces, which were taken with a digital camera. All of these face images were presented in good resolution (72 ppi) at a size of approximately 7 × 10 cm and were matched in viewpoint, lighting, and facial expression.

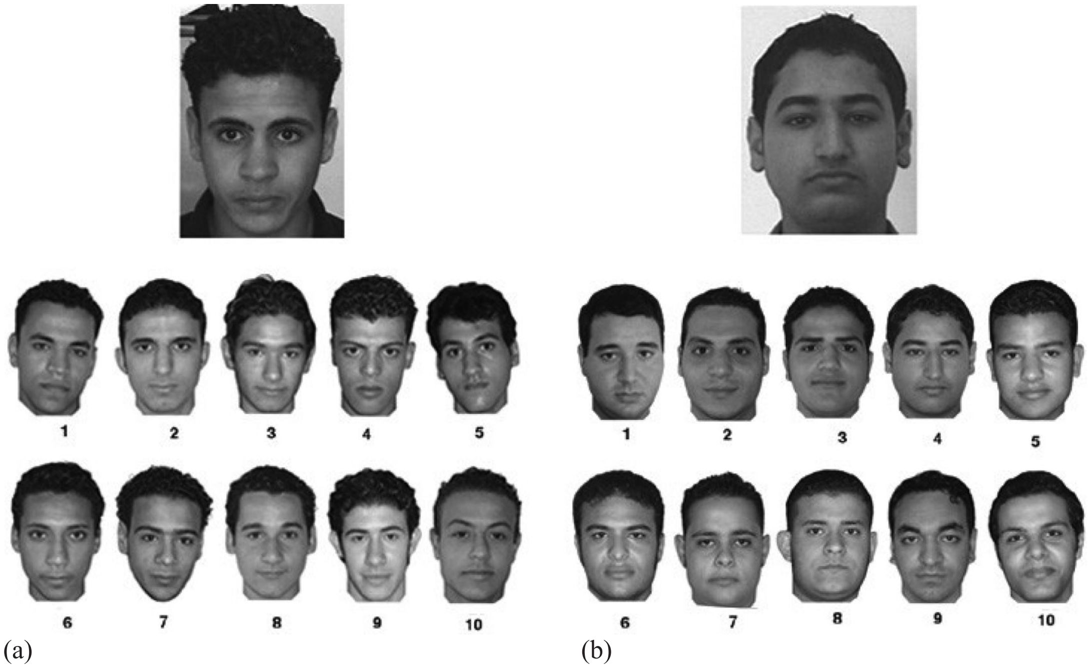


Figure 2. Examples of the 1-in-10 face matching arrays that were used in this study. The person shown at the top may or may not be one of the ten below. The target is not present in (a) and is lineup face 4 in (b).

For each of the stimulus displays a target-present and a target-absent lineup were constructed. In target-present arrays the photograph of the target face and its counterpart in the lineup were recorded on the same day to eliminate transient differences in, for example, hairstyle, health, weight, or age. The lineup location of the targets was also counterbalanced so they were equally likely to appear in each of the ten lineup locations. The target-absent displays were identical to target-present stimuli, with the exception that the target faces were replaced in the lineups with a foil. For further details see Megreya and Burton (2008).

2.1.3 *Procedure.* Participants were tested individually. The experimental materials were presented in booklets at a rate of one stimulus display per page. Two booklets were constructed to counterbalance the presence and absence of targets, so that the same target was never encountered twice (ie in a target-present and a target-absent display) by the same participant. However, over the course of the experiment, each target face was seen equally often in a target-present and a target-absent array.

Each participant completed 50 trials (25 target present and 25 target absent), which were presented in a random order. The participants were asked to match the identity of the target face to its counterpart in the 10-face lineup. They were instructed that the target might be present or absent in each display. Participants recorded their responses on an answer sheet by writing the number of the lineup face that was identified as the target or by marking the target as absent. The task was self-paced, and participants were encouraged to perform as accurately as possible. All children between 7 and 10 years of age were given five practice trials for which feedback was provided.

2.2 *Results*

Performance for target-present and target-absent lineups reflects dissociable abilities (Megreya & Burton, 2007), so these conditions were analyzed separately. For target-present and target-absent lineups the percentage of correct identifications of the target and the incorrect acceptance (false positives) of lineup faces as the target were calculated, respectively. These data are provided in table 2. A series of independent-samples *t*-tests did not find sex differences in any of the age groups (all ts $\leqslant 1$, all ps > 0.05). In addition, a series of one-sample Kolmogorov–Smirnov tests revealed that participants' performance was distributed normally around the group means (Zs ranged from 0.54 to 1.2, all ps > 0.05). Finally, a series of one-sample *t*-tests showed that correct identifications of the target and correct rejections of target-absent lineups (ie the complement of false positives) in all age groups were higher than a chance level of 10% (all ts > 17.15, all ps < 0.01).

Table 2. Descriptive statistics for face matching performance across age groups in experiment 1.

Age group/years	Correct identifications		False positives		d'		criterion	
	mean	SD	mean	SD	mean	SD	mean	SD
7	41.3	11.5	54.6	15.4	–0.34	0.54	0.05	0.25
10	51.8	14.4	38.4	20.1	0.40	0.71	0.15	0.36
13	61.7	14.3	37.2	21.9	0.69	0.90	0.02	0.33
16	74.7	12.9	31.5	21.5	1.30	0.86	–0.08	0.38
19	79.0	14.7	28.6	20.5	1.51	1.04	–0.11	0.37
35	74.8	16.0	31.8	23.3	1.36	1.01	–0.13	0.47
65	62.7	13.3	55.4	30.5	0.18	0.95	–0.27	0.52

To compare the age groups directly, two one-way between-subjects analyses of variance (ANOVAs) were conducted for target-present and target-absent trials. These ANOVAs showed a main effect of age for correct identifications ($F_{6,323} = 44.66$, $p < 0.001$, $\eta_p^2 = 0.55$) and false positives ($F_{6,323} = 11.23$, $p < 0.001$, $\eta_p^2 = 0.17$). To analyze performance for different ages, Tukey HSD tests were conducted to compare adjacent age groups (see table 3). These comparisons showed that hit rates increased between the ages of 7 and 16 years; were equivalent for the 16, 19, and 35 year age groups; and then declined in adults aged 65 years. In contrast, false positives decreased until the age of 10 years, then remained constant until the age of 35 years, but increased again in 65-year-olds.

A similar pattern emerges when correct identifications and false positives are converted into the signal detection measures of d' and criterion (see table 2). A one-factor between-subjects ANOVA showed an effect of age for d' ($F_{6,323} = 28.99$, $p < 0.001$, $\eta_p^2 = 0.35$) and criterion ($F_{6,323} = 5.57$, $p < 0.01$, $\eta_p^2 = 0.09$). Tukey comparisons of adjacent age groups are summarized in table 3 and confirm that accuracy (d') increases between 7 and 10 years and also between 13 and 16 years of age; is comparable for 16, 19, and 35-year-olds; and declines in 65-year-olds. criterion shows that a bias to make positive person identifications develops continuously with age and is most pronounced in the oldest adults. However, none of the comparisons between adjacent age groups was significant (see table 3).

Table 3. Tukey HSD comparisons for face matching performance across adjacent age groups in experiment 1. Note: * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$.

Age group/ years	Correct identifications		False positives		d'		criterion	
	Tukey's q	Cohen's d	Tukey's q	Cohen's d	Tukey's q	Cohen's d	Tukey's q	Cohen's d
7 vs 10	5.14**	0.81	4.92*	0.91	5.74**	1.17	1.59	0.32
10 vs 13	4.81*	0.69	0.36	0.06	2.25	0.36	2.16	0.37
13 vs 16	6.35**	0.96	1.73	0.26	4.74*	0.69	1.71	0.28
16 vs 19	2.11	0.31	0.90	0.14	1.63	0.22	0.59	0.08
19 vs 35	2.07	0.27	0.97	0.15	1.17	0.14	0.28	0.05
35 vs 65	5.89**	0.82	7.17**	0.87	9.14*	1.20	2.39	0.28

2.3 *Discussion*

This experiment explored age-related changes in face matching using the 1-in-10 task. There were remarkable increases in correct target identifications through the ages of 7 to 16 years. Thereafter, the percentage of correct identifications did not differ between the ages of 16, 19, and 35 years. A similar, but not identical, pattern was observed for target-absent lineups. For this measure, false positives decreased between 7 and 10 years of age, but then remained stable until the age of 35 years. Thus, performance for target-absent lineups reached adult-like levels earlier than correct identifications, at 10 compared with 16 years of age. Finally, between the age of 35 and 65 years, correct identifications declined and false positives increased, but the increase in the latter (23.6%) exceeded the decrease in the former (12.1%).

These age-related changes in face matching ability converge with studies of face recognition memory, which have also shown improvements in correct identifications and a decrease in false positives with development (eg, Chance & Goldstein, 1984; Chung & Thomson, 1995; Shapiro & Penrod, 1986) and a reverse of this trend during later adulthood (Bäckman, 1991; Bartlett et al., 1991, 2009; Boutet & Faubert, 2006; Germine et al., 2011; Lamont et al., 2005). While these effects may reflect developmental improvements and a later decline in *memory*, a similar pattern has been found for correct identification with the BFRT, which provides a more direct test of *face* perception (Carey et al., 1980; de Heering et al., 2012; Searcy et al., 1999). Experiment 1 replicates these findings with another direct test of face matching, in which memory factors are minimized, and extends previous results to target-absent trials.

3 Experiment 2

Experiment 1 shows a developmental improvement in face matching during childhood and a decline in later adulthood. A possible explanation for these effects may lie in the difficulty of the task, which might put a particular strain on younger and older age groups. This difficulty arises in part from the number of comparisons that are required to contrast a target to each of the ten lineup faces as accuracy improves with reduced lineups of five faces (see Bindemann et al., 2012; Megreya, Bindemann, Havard, & Burton, 2012). Performance is even better when this task is reduced to a simple pair-matching scenario, in which observers have to decide whether two concurrent faces depict the same person or two different people (Megreya & Burton, 2006b, 2008). In experiment 2 we therefore sought to replicate our findings with such a 1-to-1 pairwise matching task. Our aim here was to determine whether the developmental disadvantage and the age-related decline in face matching persist when task difficulty is reduced in this way.

In an additional step, we also compared matching for upright faces with inverted faces that are turned upside down. Such inversion impairs face perception across a wide range of tasks. This is held to reflect a disruption of normal face processes, whereby inverted faces are processed in a manner that is more similar to general object processing (see, eg, de Gelder & Rouw, 2000; Farah, Wilson, Drain, & Tanaka, 1995; Moscovitch, Winocur, & Behrmann, 1997). The absence of an inversion effect is also taken as evidence that the face-processing system is damaged or underdeveloped (see, eg, Behrmann & Avidan, 2005; de Gelder & Rouw, 2000; Duchaine, Yovel, Butterworth, & Nakayama, 2006). If the developmental disadvantage and the age-related decline that were observed in experiment 1 reflect an impairment of face-specific processes, then performance for upright and inverted faces should be comparable in the affected groups (eg, the 7- and 65-year-olds). If, on the other hand, these face processes are intact but simply not functioning at the level of adolescents and young and middle-aged adults, then we would expect to find a decrease in accuracy in the youngest and oldest observers but also an inversion effect. The inverted face condition therefore allows us to explore whether the developmental disadvantage and age-related decline reflect a qualitative shift in the manner that faces are processed or a quantitative effect.

3.1 *Method*

3.1.1 *Participants.* A total of 200 Egyptian participants volunteered for this experiment. As in experiment 1, these participants consisted of children; adolescents; and young, middle-aged. and older adults, who were recruited from primary and secondary schools and Menoufia University. However, none of these participants had taken part in experiment 1. These participants were assigned to five groups, with ages from 7 to 65 years (see table 4). All participants had normal or corrected-to-normal vision and self-reported to be in good health. As in experiment 1, parental consent for participation for child and adolescent participants was obtained prior to the experiment.

Table 4. Summary statistics for the seven age groups of the participant sample in experiment 2.

Age group/years	*N*	Sex		Age (SD)
		male	female	
7	40	18	22	7.0 (0.4)
10	40	20	20	9.8 (0.5)
13	40	20	20	13.2 (0.3)
19	40	14	26	19.2 (0.4)
65	40	26	14	65.6 (0.3)

3.1.2 *Stimuli.* The stimuli comprised a total of 160 face pairs, which depicted unfamiliar faces. As in experiment 1, all face stimuli were taken from Megreya and Burton's (2008) Egyptian face-matching database. Half of these face pairs depicted identity matches, in which two different photographs of the same person were shown. The other half consisted of identity mismatches, in which two different people were depicted. In each match and mismatch display one face image was taken with a high-quality digital camera whereas the other consisted of a still frame from high-quality video footage. In all of these pictures the faces were shown in a frontal view, with a neutral expression, and any extraneous background was removed. To produce the inverted face conditions, each of these stimulus pairs was turned upside down. This resulted in a total of 320 experimental displays, comprising 80 match and 80 mismatch pairs in the upright and the inverted face conditions. Example stimuli are shown in figure 3.

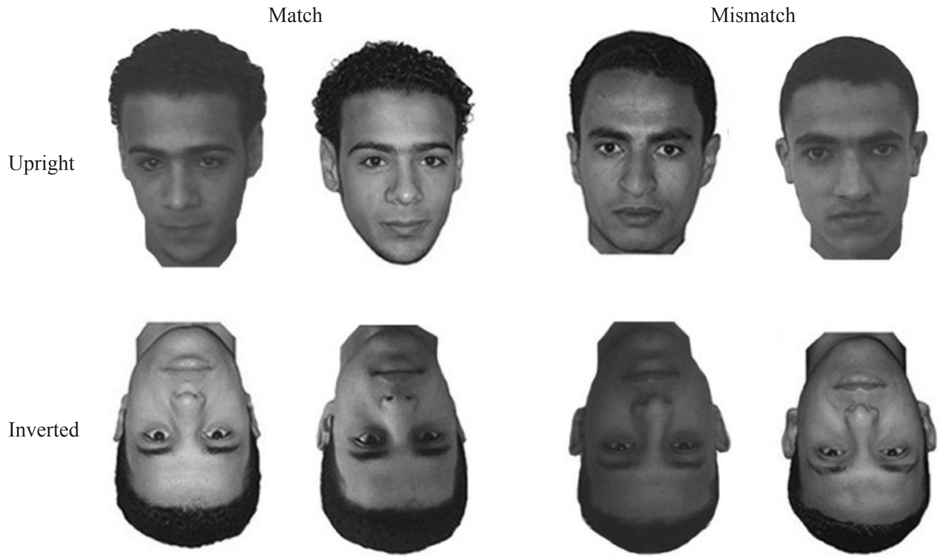


Figure 3. Examples of the face pairs used in experiment 2.

3.1.3 *Procedure.* In the experiment the stimuli were presented in a booklet at a rate of one face pair per page. Observers were asked to decide whether the two faces in a pair showed one person or two different people and recorded their responses on an answer sheet. To limit task duration and to ensure that each target identity was shown only once to each observer in any of the conditions, each participant was shown only 80 of the 320 stimuli. These 80 trials consisted of 20 match and 20 mismatch pairs for the upright and the inverted condition. However, over the course of the experiment the presentation of face pairs was counterbalanced across participants (in four separate booklets) so that each stimulus appeared equally often in each condition (upright, inverted, match, mismatch) and each age group. Within age groups, participants were randomly assigned to these four booklets.

3.2 *Results*

The mean percentage responses for match trials (correct identifications) and for mismatch trials (false positives) are shown in table 5 as a function of face orientation and age. A series of independent-samples *t*-tests did not find sex differences in any of the age groups for the upright and inverted face conditions in both correct identifications and false positives (all ts $\leqslant 1$, all ps > 0.05). In addition, a series of one-sample Kolmogorov–Smirnov tests revealed that these data were distributed normally around the group means (Zs ranged from 0.46 to 0.98, all ps > 0.05). Finally, a series of one-sample *t*-tests showed that correct identifications and correct rejections (the complement of false positives) were higher in all age groups than a chance level of 50% (all ts > 2.23, all ps < 0.05).

To compare matching performance across age groups, correct identifications and false positives were subjected to separate 2 (upright vs inverted) × 5 (7-, 10-, 13-, 19-, and 65-year-olds) mixed-factor ANOVAs. For correct identifications, main effects of age ($F_{4,195} = 7.42$, $p < 0.001$, $\eta_p^2 = 0.45$) and orientation ($F_{1,195} = 176.89$, $p < 0.001$, $\eta_p^2 = 0.48$) and an interaction between these factors were found ($F_{4,195} = 5.49$, $p < 0.001$, $\eta_p^2 = 0.10$). Table 6 reports Tukey HSD tests between adjacent age groups. For upright face pairs these comparisons show that correct identifications increased between the ages of 10 and 13 years and then declined between 19 and 65 years. The percentage of false positives showed a decline between 7 and 13 years of age and an increase between 19 and 65 years. By contrast, performance for inverted face pairs appeared to be largely consistent across age groups. Tukey HSD revealed only a decrease of false positives between the ages of 7 and 10 years. No other comparisons were significant (see table 6).

Table 5. Descriptive statistics for face matching performance as a function of participant age and face orientation in experiment 2.

Age group/years	Correct identifications				False positives			
	upright		inverted		upright		inverted	
	M	SD	*M*	SD	*M*	SD	*M*	SD
7	74.6	12.5	68.7	11.7	40.8	13.0	46.1	11.0
10	68.2	12.4	61.0	10.9	27.5	12.7	33.5	11.8
13	80.7	12.3	69.6	13.6	15.4	9.7	30.0	15.0
19	85.0	13.0	69.6	11.8	22.6	12.7	33.9	12.3
65	72.7	14.2	64.5	15.4	34.4	12.9	39.4	15.9
	d'				criterion			
	upright		inverted		upright		inverted	
	M	SD	*M*	SD	*M*	SD	*M*	SD
7	0.97	0.45	0.62	0.40	–0.23	0.31	–0.21	0.25
10	1.17	0.51	0.75	0.46	0.07	0.32	0.08	0.24
13	2.08	0.71	1.16	0.65	0.07	0.30	0.01	0.36
19	1.96	0.71	0.98	0.49	–0.16	0.30	–0.05	0.24
65	1.13	0.61	0.71	0.56	–0.13	0.36	–0.06	0.37

Table 6. Tukey HSD comparisons for face matching performance across adjacent age groups in experiment 2.

Age group/years	Correct identifications		False positives		*d'*	
	Tukey's *q*	Cohen's *d*	Tukey's *q*	Cohen's *d*	Tukey's *q*	Cohen's *d*
Upright faces						
7 vs 10	2.42	0.51	5.14**	1.03	1.76	0.41
10 vs 13	4.74**	1.01	4.70**	1.07	7.99***	1.47
13 vs 19	1.61	0.34	2.81	0.64	1.03	0.17
19 vs 65	4.65*	0.90	4.55*	0.92	7.27***	1.25
Inverted faces						
7 vs 10	2.94	0.68	4.89**	1.10	1.14	0.30
10 vs 13	3.27	0.70	1.36	0.24	3.61	0.73
13 vs 19	0.00	0.00	1.50	0.28	1.61	0.31
19 vs 65	1.95	0.37	2.13	0.39	2.32	0.51
Upright vs inverted faces						
7	5.16**	0.49	4.31**	0.44	6.40***	0.82
10	6.37**	0.62	4.81**	0.49	7.73***	0.86
13	9.77**	0.86	11.73**	1.15	16.97***	1.35
19	13.51**	1.24	9.03**	0.90	18.18***	1.61
65	7.25**	0.55	4.01**	0.34	7.73***	0.72

* $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$.

In addition, a consistent inversion effect was found across all age groups, in both correct identifications and false positives (see table 5). The sizes of these inversion effects were also calculated directly across all age groups, by subtracting performance for inverted from upright face displays, and subjected to two one-way between-subjects ANOVAs. This revealed a main effect for correct identifications ($F_{4,195} = 5.49$, $p < 0.001$, $\eta_p^2 = 0.10$) and false positives ($F_{4,195} = 5.90$, $p < 0.001$, $\eta_p^2 = 0.11$). For correct identifications Tukey HSD comparisons showed a larger inversion effect in 19-year-old adults than in 7-year-olds ($q = 5.90$, $p < 0.001$, Cohen's $d = 1.01$), 10-year-olds ($q = 5.05$, $p < 0.01$, Cohen's $d = 0.87$), and 65-year-old adults ($q = 4.43$, $p < 0.05$, Cohen's $d = 0.62$). For false positives, a Tukey HSD test showed a larger inversion effect in 13-year-olds than in 7-years-olds ($q = 5.25$, $p < 0.01$, Cohen's $d = 0.76$), 10-year-olds ($q = 4.89$, $p < 0.01$, Cohen's $d = 0.78$), and 65-year-old adults ($q = 5.46$, $p < 0.01$, Cohen's $d = 0.77$). No other differences were significant.

Finally, as in experiment 1, the percentage accuracy data were also converted into d' and criterion to examine possible response biases (see table 5). For d' a 2 (upright vs inverted) × 5 (7-, 10-, 13-, 19-, and 65-year-olds) mixed-factor ANOVA showed a main effect of age ($F_{4,195} = 20.72$, $p < 0.001$, $\eta_p^2 = 0.30$) and face orientation ($F_{1,195} = 325.01$, $p < 0.001$, $\eta_p^2 = 0.27$) and an interaction between these factors ($F_{4,195} = 16.13$, $p < 0.001$, $\eta_p^2 = 0.07$). Tukey HSD comparisons of adjacent age groups are summarized in table 6. For upright face pairs, these comparisons show that accuracy increased between the ages of 10 and 13 years and declined between 19 and 65 years. For inverted faces no differences between age groups were found. However, d' also confirmed the clear face inversion effect in all age groups. Analysis of criterion also revealed a main effect of age ($F_{4,195} = 8.02$, $p < 0.001$, $\eta_p^2 = 0.14$), but not of face orientation, and found no interaction between factors (both Fs < 1). As in experiment 1, Tukey HSD tests failed to find differences in criterion between adjacent age groups (all qs $\geqslant 1.05$).

3.3 *Discussion*

This experiment aimed to replicate the findings of experiment 1 with a less difficult task, by reducing the 1-in-10 displays to a 1-to-1 comparison. This manipulation was clearly successful. Correct identifications, for example, improved for 7-year-olds from 41% in experiment 1 to 75% in experiment 2, and for 19-year-olds from 79% to 85%. Despite these differences between experiments, we again observed a developmental improvement and an age-related decline. This improvement continued into adolescence in both correct identifications and false positives, but then deteriorated again by the age of 65 years. These findings are remarkable because the current paradigm provides a highly optimized test for the perceptual identification of unfamiliar faces (see, eg, Burton et al., 2010; Megreya & Burton, 2006b, 2007, 2008). These results therefore rule out that the pattern of experiment 1 arises simply from the difficulty of the 1-in-10 task.

We also compared face matching for upright with inverted faces to explore whether these age effects reflect a qualitative shift in the manner that faces are processed or a quantitative effect (see, eg, Behrmann & Avidan, 2005; de Gelder & Rouw, 2000; Duchaine et al., 2006). This manipulation revealed a consistent inversion effect for match and mismatch face pairs across all age groups, but this was most pronounced in adolescents and young adults (13- and 19-year-olds). This indicates that the drop in accuracy that is found with the youngest and oldest participants here does not reflect an impaired reliance on face-specific processes. Instead, these findings suggest that these typical face processes are intact in the younger and oldest observers here, but are simply not functioning at the level of adolescents and young adults.

4 General discussion

This study examined age-related changes in the perceptual processing of faces with two matching tasks. In experiment 1 participants from seven age groups, ranging from 7 to 65 years, were asked to match unfamiliar face targets to lineups of 10 faces. In this task a continuous developmental improvement in face matching was found between the ages of 7 and 16 years in the ability to identify the targets from lineups (ie, correct identifications). By the age of 16 years, adolescent observers appeared to have reached performance levels that are comparable with 19- and 35-year-old adults. However, this ability then declined again by the age of 65. A slightly different pattern was observed for the correct rejection of lineups that did not include the target. In these cases performance also improved from 7 to 10 years of age, but then remained constant throughout adolescence and early and middle adulthood. However, similar to correct identifications, the ability to notice the absence of a target from a lineup also deteriorated by the age of 65 years. Both measures therefore show a developmental improvement, albeit along different trajectories, and an age-related decline in face matching ability.

In experiment 2 participants from five age groups, also ranging from 7 to 65 years, were then presented with pairs of faces that required simple identity match or mismatch decisions. For both types of decisions this task showed a developmental improvement between 7 and 13 years of age and an age-related decline for 65-year-old observers. In addition, experiment 2 also compared performance for pairs of upright and inverted faces to explore whether the impairment in children and older adults arises from a qualitative shift in the manner that faces are processed or a quantitative effect (see, eg, Behrmann & Avidan, 2005; de Gelder & Rouw, 2000; Duchaine et al., 2006). Previous studies show that the face inversion effect emerges from the age of 3 years (Picozzi, Cassia, Turati, & Vescovo, 2009; Sangrigoli & de Schonen, 2004). In the current study the face inversion effect was also consistently found across all age groups. This finding suggests that the youngest and the oldest participants, despite their impaired performance, also rely on face-specific processes to complete the matching tasks. However, the inversion effect was most pronounced in 13- and 19-year-olds. This indicates that the level at which these processes are generally functioning appears to be impaired in pre-adolescent children and older adults.

These findings converge with previous research that has employed the BFRT to study developmental improvements in face perception (Carey et al., 1980; de Heering et al., 2012). However, the exact age at which adult-like levels of performance emerge appears to vary somewhat across studies. de Heering et al. (2012) found, for example, that accuracy on the BFRT increased during childhood (~7–10 years of age), and between early adolescence (~10–12 years of age) and early adulthood (19 years of age). By contrast, Carey et al. (1980) observed already adult-like performance in 16-year-old adolescents. We also found some variation in our study, whereby adult-like levels of performance in correct identifications were reached at an earlier age in experiment 2, at 13 years, than in experiment 1. In the current study it is possible that this reflects the difficulty of the different tasks. For example, whereas 7-year-olds recorded correct identifications on only 41% of trials in experiment 1 compared with 75% in experiment 2, this difference had narrowed to 62% and 81% by the age of 13 years, and performance was much more comparable, at 79% and 85%, in 19-year-olds. Thus, this suggests that children and adolescents might reach adult-like levels in face matching performance later during development under more difficult task conditions.

Interestingly, these developmental changes in correct identifications in experiments 1 and 2 do not seem to support the encoding overload hypothesis (Pozzulo & Lindsay, 1998). According to this theory, the delayed onset of adult-like identification rates in face recognition experiments, as compared with eyewitness identification studies, can be attributed to the larger numbers of faces that need to be encoded in this type of study. Seemingly in line with this reasoning, it has already been shown that memory load (the number of targets shown in the initial learning phase) rather than recognition load (the total number of target and distractor faces shown in the subsequent recognition phase) accounts for the decline in recognition memory for unfamiliar faces (Metzger, 2002; Podd, 1990). However, these memory load effects seem to occur independently of the age of participants (Metzger, 2002). Moreover, the current study revealed developmental improvements in correct identifications with a task in which only one target had to be encoded at a time and memory loads were minimized. This indicates that the delayed onset of adult-like identification rates in face recognition experiments cannot be attributed to the memory load of these tasks. Further research is clearly required to examine why correct identifications reach maturation later in face recognition tasks than eyewitness paradigms.

In contrast to previous matching studies that have explored age effects in face perception (Carey et al., 1980; de Heering et al., 2012), our paradigms also measured correct rejections and false positives. There is a general consensus that correct identifications increase dramatically, and false positives decrease, prior to or during adolescence in face recognition (see, eg, Chung & Thomson, 1995; Shapiro & Penrod, 1986) and eyewitness identification (eg, Bartlett & Memon, 2006; Havard, 2014; Pozzulo & Lindsay, 1998). The present study provides a further replication of this finding but with perceptual tasks in which memory factors are minimized. This indicates that a difficulty in encoding unfamiliar faces in the first place, independent of any memory-related problems, contributes to problems in eyewitness identification in children. This is interesting as researchers have already attempted to improve the reliability of eyewitness identifications in children by implementing procedural changes such as elimination lineups (Pozzulo & Lindsay, 1999) or the inclusion of a "not sure" response option (Brewer, Keast, & Sauer, 2010). The current findings suggest that attempts to improve the accuracy of eyewitness identification in children also need to focus on assessing their ability to encode unfamiliar faces in the first place (for similar approaches with adult observers see, eg, Bindemann, Avetisyan, & Rakow, 2012; Bindemann et al., 2012; Geiselman et al., 2001; Hosch, 1994).

In addition to the developmental improvements in face matching, experiments 1 and 2 also recorded a decline in matching accuracy in later adulthood, in 65-year-old observers. These detrimental aging effects converge with previous studies on face recognition memory (Bäckman, 1991; Bartlett et al., 1991, 2009; Boutet & Faubert, 2006; Germine et al., 2011; Lamont et al., 2005) and eyewitness identification (Memon et al., 2003; Searcy et al., 1999, 2001). A similar decline has also been observed with other identification paradigms, such as sequential (Meinhardt-Injac, Persike, & Meinhardt, 2014a) and simultaneous matching tasks (Benton et al., 1981; Searcy et al., 1999). Our experiments extend these studies by applying a direct test for the perceptual processing of faces that includes target-absent lineups (experiment 1) and identity-mismatch face pairs (experiment 2). Similarly to the developmental improvements in childhood and early adolescence, our findings therefore indicate that the age-related decline in face recognition and eyewitness identification can be observed when memory demands are minimized. This indicates that this age-related decline arises during the perceptual encoding of unfamiliar faces.

It is noteworthy that some researchers have previously argued against this suggestion on the basis that false positives in eyewitness identification remain high in older adults who also perform well on the BFRT (Searcy et al., 1999). However, such false positives could reflect identification errors that arise from a misplaced sense of familiarity (see, eg, Bartlett & Fulton, 1991; Edmonds et al., 2012; Rhodes et al., 2008). It has emerged subsequently that correct identifications and false positives reflect dissociable processes, whereby the ability to identify a person from a lineup is unrelated to the ability to reject an identity lineup without this person (Bruce et al., 1999; Burton et al., 2010; Megreya & Burton, 2006b, 2007).

This indicates that it is inappropriate to use a measure of correct identifications, such as performance on the BFRT, to support inferences about an observer's tendency to record false positives.

The question remains of the cause of the developmental face processing disadvantage in children and also the decline in older adults. Studies of face matching with sequential identification tasks suggest that developmental effects reflect improvements with age in holistic processing, which allows for the combination of separate facial features (eg, the eyes, nose, and mouth) into integrated percepts (Meinhardt-Injac, Persike, & Meinhardt, 2014b). This appears to be a face-specific improvement that is distinct from general cognitive or perceptual abilities (see, eg, Meinhardt-Injac et al., 2014b; Picozzi et al., 2009). By contrast, the age-related decline has been linked to a specific difficulty to process internal facial features rather than an impairment of holistic processes (Daniel & Bentin, 2012; Meinhardt-Injac et al., 2014a). This might reflect particular problems in processing information from the eyes, as older adults appear to be impaired in detecting changes to this face region (Chaby, Jemel, George, Renault, & Fiori, 2001).

It is possible that an age-related impairment to process the eye regions could also reflect an attentional effect. Older adults appear to have difficulty in attending the local elements of Navon letters (Pesce, Guidetti, Baldari, Tessitore, & Capranica, 2005; Roux & Ceccaldi, 2001), which has been compared with the processing of facial features during person identification (see, eg, Darling, Martin, Hellmann, & Memon, 2009; Macrae & Lewis, 2002; Perfect, 2003). It has also been shown that older adults focus less on the eye regions of faces (Slessor, Phillips, & Bull, 2008; Sullivan, Ruffman, & Hutton, 2007). The eyes are consistently the most fixated feature in faces (see, eg, Althoff & Cohen, 1999; Bindemann, Scheepers, & Burton, 2009; Henderson, Williams, & Falk, 2005), and an inability to utilize these features has already been linked to impairments in face processing (Caldara et al., 2005). Thus, the age-related decline in face matching could also reflect a failure to attend to important visual information from the eyes.

In summary, the current study provides direct evidence from identity matching paradigms that the widely documented age-related changes in face recognition occur during the perceptual encoding of faces. These effects were accompanied in all age groups by a consistent inversion effect. This indicates that even the youngest and oldest participants, despite their impaired performance, rely on face-specific processes to complete the matching tasks. However, the level at which these processes are generally functioning appears to be impaired in observers below the ages of 16 years (experiment 1) or 13 years (experiment 2) and in 65-year-old adults (experiments 1 and 2). We attribute the difference in the age at which this disadvantage disappeared in children to the difficulty of our different tasks.

The precise age at which face recognition generally reaches maturation does, in fact, remain controversial. It has been argued that all qualitative (for a review see, eg, McKone, Crookes, & Kanwisher, 2009) and quantitative aspects (Crookes & McKone, 2009) of adult-like face recognition are present in young children at 5–7 years of age at the latest. According to this view, any developmental increases in face recognition reflect improvements in general cognitive mechanisms such as concentration, visual attention, and explicit memory ability (see, eg, Crookes & McKone, 2009). However, it has also been suggested that recognition memory for names and inverted faces reaches maturation in the early 20s, whereas the ability to learn and recognize unfamiliar faces peaks later, in the early 30s (Germine et al., 2011). In a recent study Meinhardt-Injac et al. (2014b) demonstrate that improvements in face perception continue into the second decade of life and are distinct from improvements in object perception. Consequently, it seems that improvements in face recognition cannot be accounted for by general cognitive factors. The present study adds to this debate by demonstrating that face matching reaches adult-like levels of performance at an earlier age than face memory, between 13 and 16 years of age (cf, eg, Germine et al., 2011). These results appear to converge with neuroimaging studies, which have revealed significant expansions of face-selective brain areas between childhood and adolescence (Aylward et al., 2005), whereas adolescents then show more adult-like patterns of face-selective brain activation (Scherf, Behrmann, Humphreys, & Luna, 2007).

References

Althoff, R. R., & Cohen, N. J. (1999). Eye-movement-based memory effect: A reprocessing effect in face perception. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **25**, 997–1010. doi:10.1037/0278-7393.25.4.997

Aylward, E. H., Park, J. E., Field, K. M., Parsons, A. C., Richards, T. L., Cramer, S. C., & Meltzoff, A. N. (2005). Brain activation during face perception: Evidence of a developmental change. *Journal of Cognitive Neuroscience*, **17**, 308–319. doi:10.1162/0898929053124884

Bäckman, L. (1991). Recognition memory across the adult life span: The role of prior knowledge. *Memory & Cognition*, **19**, 63–71. doi:10.3758/BF03198496

Bartlett, J. C. (1993). Limits on losses in face recognition. In J. Cerella, J. Rybash, W. Hoyer, & M. L. Commons (Eds.), *Adult information processing: Limits on loss* (pp. 351–379). New York: Academic Press.

Bartlett, J. C., & Fulton, A. (1991). Familiarity and recognition of faces in old age. *Memory & Cognition*, **19**, 229–238. doi:10.3758/BF03211147

Bartlett, J. C., & Memon, A. (2006). Eyewitness memory in young and older adults. In R. Lindsay, R. Ross, D. Read, & M. Toglia (Eds.), *Handbook of eyewitness psychology: Memory for people* (pp. 309–338). Mahwah, NJ: Lawrence Erlbaum Associates.

Bartlett, J. C., Shastri, K. K., Abdi, H., & Neville-Smith, M. (2009). Component structure of individual differences in true and false recognition of faces. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **35**, 1207–1230. doi:10.1037/a0016368

Bartlett, J. C., Strater, L., & Fulton, A. (1991). False recency and false fame of faces in young adulthood and old age. *Memory & Cognition*, **19**, 177–188. doi:10.3758/BF03197115

Beal, C. R., Schmitt, K. L., & Dekle, D. J. (1995). Eyewitness identification of children: Effects of absolute judgements, nonverbal response options, and event encoding. *Law & Human Behavior*, **19**, 197–216. doi:10.1007/BF01499325

Behrmann, M., & Avidan, G. (2005). Congenital prosopagnosia: Face-blind from birth. *Trends in Cognitive Sciences*, **9**, 180–187. doi:10.1016/j.tics.2005.02.011

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

Benton, A. L., Eslinger, P. J., & Damasio, A. R. (1981). Normative observations on neuropsychological test performance in old age. *Journal of Clinical Neuropsychology*, **3**, 33–42. doi:10.1080/01688638108403111

Bindemann, M., Avetisyan, M., & Rakow, T. (2012). Who can recognize unfamiliar faces? Individual differences and observer consistency in person identification. *Journal of Experimental Psychology: Applied*, **18**, 277–291. doi:10.1037/a0029635

Bindemann, M., Brown, C., Koyas, T., & Russ, A. (2012). Individual differences in face identification postdict eyewitness accuracy. *Journal of Applied Research in Memory and Cognition*, **1**, 96–103. doi:10.1016/j.jarmac.2012.02.001

Bindemann, M., Sandford, A., Gillatt, K., Avetisyan, M., & Megreya, A. M. (2012). Recognizing faces seen alone or with others: Why are two heads worse than one? *Perception*, **41**, 415–535. doi:10.1068/p6922

Bindemann, M., Scheepers, C., & Burton, A. M. (2009). Viewpoint and center of gravity affect eye movements to human faces. *Journal of Vision*, **9**(2):7, 1–16. doi:10.1167/9.2.7

Boutet, I., & Faubert, J. (2006). Recognition of faces and complex objects in younger and older adults. *Memory & Cognition*, **34**, 854–864. doi:10.3758/BF03193432

Brewer, N., Keast, A. L., & Sauer, J. (2010). Children's eyewitness identification performance: Effects of a *Not Sure* response option and accuracy motivation. *Legal and Criminological Psychology*, **15**, 261–277. doi:10.1348/135532509X474822

Bruce, V., Henderson, Z., Greenwood, K., Hancock, P. J. B., Burton, A. M., & Miller, P. (1999). Verification of face identities from images captured on video. *Journal of Experimental Psychology: Applied*, **5**, 339–360. doi:10.1037/1076-898X.5.4.339

Burton, A. M., White, D., & McNeill, A. (2010). The Glasgow Face Matching Test. *Behavior Research Methods*, **42**, 286–291. doi:10.3758/BRM.42.1.286

Caldara, R., Schyns, P., Mayer, E., Smith, M. L., Gosselin, F., & Rossion, R. (2005). Does prosopagnosia take the eyes out of face representations? Evidence for a defect representing diagnostic facial information following brain damage. *Journal of Cognitive Neuroscience*, **17**, 1652–1666. doi:10.1162/089892905774597254

Carey, S., Diamond, R., & Woods, B. (1980). Development of face recognition: A maturational component? *Developmental Psychology*, **16**, 257–269.

Chaby, L., Jemel, B., George, N., Renault, B., & Fiori, N. (2001). An ERP study of famous face incongruity detection in middle age. *Brain and Cognition*, **45**, 357–377. doi:10.1006/brcg.2000.1272

Chance, J. E., & Goldstein, A. G. (1984). Face-recognition memory: Implications for children's eyewitness testimony. *Journal of Social Issues*, **40**, 69–85. doi:10.1111/j.1540-4560.1984.tb01094.x

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

Crookes, L., & McKone, E. (2009). Early maturity of face recognition: No childhood development of holistic processing, novel face encoding, or face-space. *Cognition*, **11**, 219–247. doi:10.1016/j.cognition.2009.02.004

Daniel, S., & Bentin, S. (2012). Age-related changes in processing faces from detection to identification: ERP evidence. *Neurobiology of Aging*, **33**, 206.e1–206.e28. doi:10.1016/j.neurobiolaging.2010.09.001

Darling, S., Martin, D., Hellmann, J. H., & Memon, A. (2009). Some witnesses are better than others. *Personality and Individual Differences*, **47**, 369–373. doi:10.1016/j.paid.2009.04.010

de Gelder, B., & Rouw, R. (2000). Paradoxical configuration effects for faces and objects in prosopagnosia. *Neuropsychologia*, **38**, 1271–1279. doi:10.1016/S0028-3932(00)00039-7

de Heering, A., Rossion, B., & Maurer, D. (2012). Developmental changes in face recognition during childhood: Evidence from upright and inverted faces. *Cognitive Development*, **27**, 17–27. doi:10.1016/j.cogdev.2011.07.001

Duchaine, B., Yovel, G., Butterworth, E. J., & Nakayama, K. (2006). Prosopagnosia as an impairment to face-specific mechanisms: Elimination of the alternative hypotheses in a developmental case. *Cognitive Neuropsychology*, **23**, 714–747. doi:10.1080/02643290500441296

Edmonds, E. C., Glisky, E. L., Bartlett, J. C., & Rapcsak, S. Z. (2012). Cognitive mechanisms of false facial recognition in older adults. *Psychology and Aging*, **27**, 54–60. doi:10.1037/a0024582

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. doi:10.1111/j.2044-835X.1990.tb00823.x

Farah, M. J., Wilson, K. D., Drain, H. M., & Tanaka, J. R. (1995). The inverted faces inversion effect in prosopagnosia: Evidence for mandatory, face-specific perceptual mechanisms. *Vision Research*, **35**, 2089–2093. doi:10.1016/0042-6989(94)00273-O

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. doi:10.1006/jecp.2001.2639

Geiselman, R. E., Tubridy, A., Blumkin, R., Schroppel, T., Turner, L., Yoakum, K., & Young, N. (2001). Benton facial recognition test scores: Index of eyewitness accuracy. *American Journal of Forensic Psychology*, **19**, 77–88.

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. doi:10.1016/j.cognition.2010.11.002

Graf, P., & Ohta, N. (Eds.). (2002). *Lifespan development of human memory*. London: MIT Press.

Habak, C., Wilkinson, F., & Wilson, H. R. (2008). Aging disrupts the neural transformations that link facial identity across views. *Vision Research*, **48**, 9–15. doi:10.1016/j.visres.2007.10.007

Havard, C. (2014). Are children less reliable at making visual identifications than adults? A review. *Psychology, Crime & Law*, **20**, 372–388. doi:10.1080/1068316X.2013.793334

Havard, C., Memon, A., Clifford, B., & Gabbert, F. (2010). A comparison of video and static photo lineups with child and adolescent witnesses. *Applied Cognitive Psychology*, **24**, 1209–1221. doi:10.1002/acp.1645

Henderson, J. M., Williams, C. C., & Falk, R. J. (2005). Eye movements are functional during face learning. *Memory & Cognition*, **33**, 98–106. doi:10.3758/BF03195300

Hosch, H. (1994). Individual differences in personality and eyewitness identification. In D. F. Ross, J. D. Read, & M. P. Toglia (Eds.), *Adult eyewitness testimony: Current trends and developments* (pp. 328–347). New York: Cambridge University Press.

Konar, Y., Bennett, P. J., & Sekuler, A. B. (2010). Holistic processing is not correlated with face-identification accuracy. *Psychological Science*, **21**, 38–43. doi:10.1177/0956797609356508

Lamont, A. C., Stewart-Williams, S., & Podd, J. (2005). Face recognition and aging: Effects of target age and memory load. *Memory & Cognition*, **33**, 1017–1024. doi:10.3758/BF03193209

Lindsay, R. C. L., Pozzulo, J. D., Craig, W., Lee, K., & Corber, S. (1997). Simultaneous lineups, sequential lineups and showups: Eyewitness identification decisions of adults and children. *Law & Human Behavior*, **21**, 391–404. doi:10.1023/A:1024807202926

Macrae, C. N., & Lewis, H. L. (2002). Do I know you? Processing orientation and face recognition. *Psychological Science*, **13**, 194–196. doi:10.1111/1467-9280.00436

McKone, E., Crookes, K., & Kanwisher, N. (2009). The cognitive and neural development of face recognition in humans. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (4th ed., pp. 467–482). Cambridge: MIT Press.

Megreya, A. M., & Bindemann, M. (2013). Individual differences in personality and face identification. *Journal of Cognitive Psychology*, **25**, 30–37. doi:10.1080/20445911.2012.739153

Megreya, A. M., Bindemann, M., Havard, C., & Burton, A. M. (2012). Identity-lineup location influences target selection: Evidence from eye movements. *Journal of Police and Criminal Psychology*, **27**, 167–178. doi:10.1007/s11896-011-9098-7

Megreya, A. M., & Burton, A. M. (2006a). Recognising faces seen alone or with others: When two heads are worse than one. *Applied Cognitive Psychology*, **20**, 957–972. doi:10.1002/acp.1243

Megreya, A. M., & Burton, A. M. (2006b). Unfamiliar faces are not faces: Evidence from a matching task. *Memory & Cognition*, **34**, 865–876. doi:10.3758/BF03193433

Megreya, A. M., & Burton, A. M. (2007). Hits and false positives in face matching: A familiarity-based dissociation. *Perception & Psychophysics*, **69**, 1175–1184. doi:10.3758/BF03193954

Megreya, A. M., & Burton, A. M. (2008). Matching faces to photographs: Poor performance in eyewitness memory (without the memory). *Journal of Experimental Psychology: Applied*, **14**, 364–372. doi:10.1037/a0013464

Megreya, A. M., White, D., & Burton, A. M. (2011). The other race effect does not rely on memory: Evidence from a matching task. *Quarterly Journal of Experimental Psychology*, **64**, 1473–1483. doi:10.1080/17470218.2011.575228

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2014a). Holistic processing and reliance on global viewing strategies in older adults' face perception. *Acta Psychologica*, **151**, 155–163. doi:10.1016/j.actpsy.2014.06.001

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2014b). Development of visual systems for faces and objects: Further evidence for prolonged development of the face system. *PLoS ONE*, **9**: e99942. doi:10.1371/journal.pone.0099942

Memon, A., Bartlett, J. C., Rose, R., & Gray, C. (2003). The aging eyewitness: The effects of face, age and delay upon younger and older observers. *Journal of Gerontology: Psychological Sciences*, **58**, 338–345.

Metzger, M. M. (2002). Stimulus load and age effects in face recognition: A comparison of children and adults. *North American Journal of Psychology*, **4**, 51–62.

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. doi:10.1016/S0022-0965(03)00102-4

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, **31**, 553–566. doi:10.1068/p3339

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience*, **9**, 555–604. doi:10.1162/jocn.1997.9.5.555

Perfect, T. J. (2003). Local processing bias impairs lineup performance. *Psychological Reports*, **93**, 393–394. doi:10.2466/PR0.93.6.393-394

Pesce, C., Guidetti, L., Baldari, C., Tessitore, A., & Capranica, L. (2005). Effects of aging on visual attentional processing. *Gerontology*, **51**, 266–276. doi:10.1159/000085123

Pezdek, K., Blandon-Gitlin, I., & Moore, C. (2003). Children's face recognition memory: More evidence for the cross-race effect. *Journal of Applied Psychology*, **88**, 760–763. doi:10.1037/0021-9010.88.4.760

Picozzi, M., Cassia, V. M., Turati, C., & Vescovo, E. (2009). The effect of inversion on 3- to 5-year-olds' recognition of face and nonface visual objects. *Journal of Experimental Child Psychology*, **102**, 487–502. doi:10.1016/j.jecp.2008.11.001

Podd, J. (1990). The effects of memory load and delay on face recognition. *Applied Cognitive Psychology*, **4**, 47–60. doi:10.1002/acp.2350040105

Pozzulo, J. D., & Balfour, J. (2006). Children's and adults' eye witness identification accuracy when a culprit changes his appearance: Comparing simultaneous and elimination line up procedures. *Legal and Criminological Psychology*, **11**, 25–34. doi:10.1348/135532505X52626

Pozzulo, J. D., & Lindsay, R. (1998). Identification accuracy of children versus adults: A meta-analysis. *Law and Human Behavior*, **22**, 549–570. doi:10.1023/A:1025739514042

Pozzulo, J. D., & Lindsay, R. (1999). Elimination lineups: An improved identification procedure for child eyewitnesses. *Journal of Applied Psychology*, **84**, 167–176. doi:10.1037/0021-9010.84.2.167

Rhodes, M. G., Castel, A. D., & Jacoby, L. L. (2008). Associative recognition of face pairs by younger and older adults: The role of familiarity-based processing. *Psychology and Aging*, **23**, 239–249. doi:10.1037/0882-7974.23.2.239

Roux, F., & Ceccaldi, M. (2001). Does aging affect the allocation of visual attention in global and local information processing? *Brain and Cognition*, **46**, 383–396. doi:10.1006/brcg.2001.1296

Sangrigoli, S., & de Schonen, S. (2004). The effect of visual experience on face processing: A developmental study of inversion and non-native effects. *Developmental Science*, **7**, 74–87. doi:10.1111/j.1467-7687.2004.00324.x

Scherf, K. S., Behrmann, M., Humphreys, K., & Luna, B. (2007). Visual category-selectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science*, **10**, F15–F30. doi:10.1111/j.1467-7687.2007.00595.x

Schwarzer, G. (2000). Development of face processing: The effect of face inversion. *Child Development*, **71**, 391–401. doi:10.1111/1467-8624.00152

Searcy, J. H., Bartlett, J. C., & Memon, A. (1999). Age differences in accuracy and choosing rates on face recognition and eyewitness identification tasks. *Memory & Cognition*, **27**, 538–552. doi:10.3758/BF03211547

Searcy, J. H., Bartlett, J. C., Memon, A., & Swanson, K. (2001). Aging and lineup performance at long retention intervals: Effects of metamemory and context reinstatement. *Journal of Applied Psychology*, **86**, 207– 214. doi:10.1037/0021-9010.86.2.207

Shapiro, P. N., & Penrod, S. (1986). Meta-analysis of facial identification studies. *Psychological Bulletin*, **100**, 139–156. doi:10.1037/0033-2909.100.2.139

Slessor, G., Phillips, L. H., & Bull, R. (2008). Age-related declines in basic social perception: Evidence from tasks assessing eye-gaze processing. *Psychology and Aging*, **23**, 812–822. doi:10.1037/a0014348

Sullivan, S., Ruffman, T., & Hutton, S. B. (2007). Age differences in emotion recognition skills and the visual scanning of emotion faces. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **62**, 53–60.

Whitbourne, S. K., & Sliwinski, M. (2012). *The Wiley-Blackwell handbook for adulthood and aging*. Oxford: Wiley-Blackwell.