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Recognition of faces and complex objects in younger and older adults

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We examined whether (1) age-associated impairments in face recognition are specific to faces or also apply to within-category recognition of other objects and (2) age-related face recognition deficits are related to impairments in encoding second-order relations and holistic information. In Experiments 1 and 2, we found reliable age differences for recognition of faces, but not of objects. Moreover, older adults (OAs) and younger adults (YAs) displayed similar face inversion effects. In Experiment 3, unlike YAs, OAs did not show the expected decline in performance for recognition of composites (Young, Hellawell, & Hay, 1987). In Experiment 4, both OAs and YAs showed a whole/part advantage (Tanaka & Farah, 1993). Our results suggest that OAs have spared function for processing of second-order relations and holistic information. Possible explanations for the finding that OAs have greater difficulty recognizing faces than recognizing other objects are proposed.

Age-related declines in recognition memory for familiar and unfamiliar faces have been widely reported (e.g., Bartlett, Strater, & Fulton, 1991; Crook & Larrabee, 1992; Maylor & Valentine, 1992). These declines are characterized by a higher proportion of false alarms to nonfamiliar faces in healthy older individuals (reviewed by Searcy, Bartlett, & Memon, 1999). It is important to examine face recognition deficits in the elderly not only because they have an impact on the social and personal lives of older individuals, but also because they have implications in the management of older eyewitnesses to crime.

Several possible explanations have been proposed for age differences in face recognition. Some have been based on memory mechanisms and have included such factors as confusion due to the increased number of faces that have been memorized with age (Chaby, Jemel, George, Renault, & Fiori, 2001), deficits in recollection of contextual information (Bartlett & Fulton, 1991; Bartlett et al., 1991; Mandler, 1980; Searcy et al., 1999), impaired memory for novel visuospatial information (Searcy et al., 1999), and difficulties in carefully matching test pictures with representations stored in memory (Bartlett, Leslie, Tubbs, & Fulton, 1989). Other explanations have been based on encoding mechanisms and have included such factors as reduced contrast sensitivity in elderly subjects (Owsley, Sekuler, & Boldt, 1981) and a reduced ability to form distinctive representations of faces (Bartlett & Fulton, 1991). Still others have focused on the interaction between the encoding and the retrieval mechanisms involved in face recognition. These have included information loss at each successive step of a computation process, which predicts more pronounced deficits for more complex abilities (Cerella, 1990; Maylor & Valentine, 1992; Salthouse, 1996a, 1996b), deficits at each stage of the face recognition process (Maylor, 1990), and an increased need for cognitive resources during performance of complex tasks, which results in higher activation of prefrontal areas (Grady, 2002).

Although support for some of these hypotheses has been reported, the interpretations proposed often have overlooked evidence that is well established in the face recognition literature. For example, it has been suggested that older adults have difficulties recognizing faces because of the reduction in contrast sensitivity associated with aging. In agreement with this hypothesis, Owsley, Sekuler, and Boldt (1981) have shown that increasing the contrast of faces can improve face recognition in this population. However, studies conducted with younger adults have shown that face recognition depends on a critical band of spatial frequencies in the middle range (reviewed by Costen, Parker, & Craw, 1996) for which sensitivity is very high and the perception of which should be least affected by low-contrast vision. Hence, although decreased contrast sensitivity may contribute to impairments in face recognition in elderly individuals, other factors must also be involved.

A more serious flaw in studies in which age differences in face recognition have been examined has been the failure to include a comparison nonface category. A number of studies have suggested that memory for objects remains relatively intact in older adults (Park, Puglisi, & Smith,

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1986; Park, Royal, Dudley, & Morrell, 1988). However, the recognition tasks previously employed failed to provide an appropriate comparison for face recognition. Face recognition is unique in two important ways: First, faces are exceptionally homogeneous and complex; second, faces are recognized at the individual level (e.g., John's face), a task requiring fine within-category discriminations. Recognition deficits in older individuals, therefore, may not be specific to faces but, rather, may extend to other objects when equivalent tasks are employed. If this is the case, deficits equivalent to those found for faces will be observed for within-category recognition of other complex objects. Such a finding would suggest that age-related face recognition deficits have little to do with face recognition per se but, rather, arise from a general deficit in recognizing individual exemplars of a homogeneous stimulus category.

Another possibility is that age-related face recognition deficits are face specific, in that they reflect impairments in mechanisms that are tailored to the idiosyncratic properties of faces. There is considerable evidence that the mechanisms involved in face recognition differ from those involved in object recognition (see the review in Maurer, Le Grand, & Mondloch, 2002). Three types of information can be used in recognition: isolated features, first-order relations, and second-order relations (Diamond & Carey, 1986; Maurer et al., 2002). Isolated features refer to the constituent parts of an object, and they can be specified without reference to other parts of the object (e.g., the eyes, nose, mouth, etc.). First-order relations refer to the spatial arrangements between isolated features (e.g., placement of the eyes above the nose, the nose above the mouth, etc.). Because they are homogeneous, all faces share the same first-order relations. Second-order relations refer to the relative size of spatial relations between parts of an object (e.g., the distance between the two eyes, the eyes and the nose, etc.) that may be specified with respect to an underlying template or schema of an average face (Rhodes, 1995; Valentine & Bruce, 1986).

Face recognition differs from object recognition because it relies more heavily on second-order relations than on isolated features. In addition to second-order relations, face recognition is believed to rely more heavily on *holistic* information, meaning that all of the information present in a face is processed as a *whole* or as a *Gestalt* (Farah, Wilson, Drain, & Tanaka, 1998; Maurer et al., 2002, p. 255). Encoding of second-order relations and holistic information may be particularly important for face recognition because faces are homogeneous and are recognized at the individual level. In contrast, recognition of objects usually takes place at the categorical level, a task that may be accomplished by identifying isolated features and first-order relations (Biederman & Kalocsai, 1998; Diamond & Carey, 1986; Moscovitch & Moscovitch, 2000). Nonetheless, there is evidence that face recognition relies more heavily on second-order relations and holistic information even when equivalent within-category tasks are used (e.g., Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Yin, 1969). Therefore, age-related face recognition deficits may arise from impairments in face-specific mechanisms, such as the processing of second-order relations and holistic information.

In the present study, four experiments were conducted to investigate whether age-related face recognition deficits reflect a general impairment in within-category recognition of complex objects or impairments in the processing of second-order relations and holistic information. We employed a variety of tests that have been successfully employed to illustrate the crucial role that second-order relations and holistic information play in face recognition. In Experiments 1 and 2, the face inversion effect (FIE) was tested. The FIE refers to the finding that face recognition is more significantly impaired by inversion than is recognition of other complex objects (see the review in Valentine, 1988). These experiments also allowed us to explore potential age differences in within-category recognition of nonface objects, because evaluation of the FIE requires that recognition of both faces and nonface objects be measured. In Experiment 3, we used the composite effect, whereby two halves from different faces are more difficult to recognize when they are horizontally aligned than when misaligned (Young, Hellawell, & Hay, 1987). In Experiment 4, we tested the whole/part advantage, whereby recognition of a face part is superior in the context of a face than in isolation (Tanaka & Farah, 1993). These tests were measured in younger adults (YAs) 18 to 35 years of age, as well as in healthy older adults (OAs) 65 years of age and over.

EXPERIMENT 1

In Experiment 1, the FIE was evaluated by comparing recognition of upright and inverted faces and nonface objects in both YAs and OAs. Houses and chairs were chosen as comparisons for faces because, as for faces, it is possible to select stimuli so that all the individual exemplars in each category share the same features arranged in the same first-order configuration. Moreover, houses and chairs are as familiar to most observers as faces are.

The FIE is characterized by an interaction between image category and orientation such that the difference between the recognition of upright versus inverted faces is more pronounced than the difference between the recognition of upright versus inverted objects. Although inversion has been shown to disrupt the processing of both second-order relations and holistic information (see the review in Maurer et al., 2002), recent studies that have carefully controlled for both of these constructs suggest that the FIE is largely attributable to a disruption in the processing of second-order relations (Leder & Bruce, 2000; Leder, Candrian, Huber, & Bruce, 2001). Recognition of inverted faces may be particularly difficult because reference points normally used to process second-order relations become difficult to extract following inversion. In contrast, nonface objects may be recognized, using salient features, even when a within-category task is employed (Moscovitch & Moscovitch, 2000). Because salient features can be easily identified whether the object is upright or inverted, inversion has little influence on the recognition of nonface objects.

Differences in the magnitude of the FIE can, therefore, provide an indication of the extent to which faces are recognized on the basis of second-order relations: If the magnitude of the FIE is comparable for YAs and OAs, one can conclude that both groups rely equally on second-order relations to recognize faces; if the FIE effect is smaller in older observers, one can conclude that younger observers rely more heavily on second-order relations when encoding faces than do older observers. A similar approach was successfully employed in studies of prosopagnosic patients who suffer from an inability to recognize familiar faces following brain damage. These patients do not display a typical FIE but, rather, perform better than normal at matching inverted faces. This finding suggests that prosopagnosics recognize faces on the basis of features, a strategy that is more robust to inversion (Farah, Wilson, Drain, & Tanaka, 1995).

Experiment 1 also allowed us to explore whether age-associated recognition deficits are present for both faces and nonface objects when equivalent within-category tasks are used. To investigate this hypothesis, only responses to upright stimuli were analyzed, because recognition of inverted stimuli has no bearing on the question of whether or not previously reported deficits in face recognition generalize to other object categories. Evidence suggests that inverted faces may trigger different encoding processes than do upright faces.

Method

Participants. Fourteen OAs (mean age, 70 years; range, 59–84 years) were recruited from the Optometry Clinic at the Université de Montréal. The mini-mental state examination (MMSE; original and French translation) (Folstein, Folstein, & McHugh, 1975) was used to evaluate mental status. The MMSE was administered on a different day than the experiment and only to those participants who could be contacted and who were willing to come back to the laboratory. Eight out of 14 participants were tested on the MMSE. The mean score for this group was 28.5 ($SD = 1.31$). Fourteen YAs (mean age, 23 years; range, 18–29 years) were recruited from the student population. The participants gave informed consent after the procedure had been explained to them. Corrected binocular acuity was 6/6 (20/20) or better for all the participants. Visual acuity measures were obtained from the participants' charts with their permission. All eye exams had been completed less than 1 year before testing. All the participants were tested with their corrective lenses. For the OAs, +1.00 lenses were fitted over the participants' regular glasses to account for viewing distance. No participants reported any visual or neurological problems. None of the participants had a history of diabetic retinopathy, glaucoma, or macular degeneration.[1]

Apparatus and Stimuli. The participants were tested individually, using a Macintosh G3/266 computer with a 21-in. Macintosh color monitor with a refresh screen rate of 75 Hz. The screen was calibrated to linearized luminance values, using a Minolta CS-100 photometer.

Two sets of stimuli were used, one for the *chair* block and one for the *house* block. The chair set consisted of 80 faces and 80 chairs. Face images were 80 digitized photographs of males obtained from a database at the University of Essex (hpl/essex.ac.uk/projects/vision/allfaces/). Chair images were taken from various Web sites and from scanned photographs. The house set consisted of 120 faces and 120 houses. Half of the face images were females, and half were males. They were obtained from the Max Planck Institute for Biological Cybernetics in Tübingen, Germany. House images were obtained from various Web sites. All the images were converted to a 256 gray-level format and cropped to fit in a 180×200 pixel window (subtending 3.72×4.00 deg of arc at a viewing distance of 1 m). Examples of the stimuli are shown in Figure 1.

Procedure. A two-alternative forced choice (2AFC) recognition paradigm was used. Two blocks were tested, a chair block and a house block. Each block consisted of four segments of one study stage, followed immediately by one testing stage. Twenty images were shown for 5 sec each during each study stage, with an interstimulus interval of 0.5 sec. The first and last two images shown during each study stage were omitted for testing, to avoid primacy and recency effects. Sixteen trials were shown for each test stage. Each test trial consisted of the presentation of one studied image, together with one new image (one on the left of the fixation point and one on the right, counterbalanced). Upon presentation of each image, the participants had to determine which image (left or right) had been shown in the previous study stage. The participants were given as much time as needed to answer. The experimenter (I.B.) entered responses. A break of 1 min was provided between each segment. Images were presented upright in half of the segments and inverted in the other half. Image orientation was the same during the study and the testing stages. Faces were presented in half of the segments and objects in the other half. Presentation order of the segments was randomized.

For the chair block, 40 faces and 40 chairs were randomly chosen from the corresponding set and used as targets during the study stage. Because many different types of chairs were used (i.e., kitchen chair, office chair, etc.), each chair target was matched with a distractor chair with similar physical characteristics. For the house block, 40

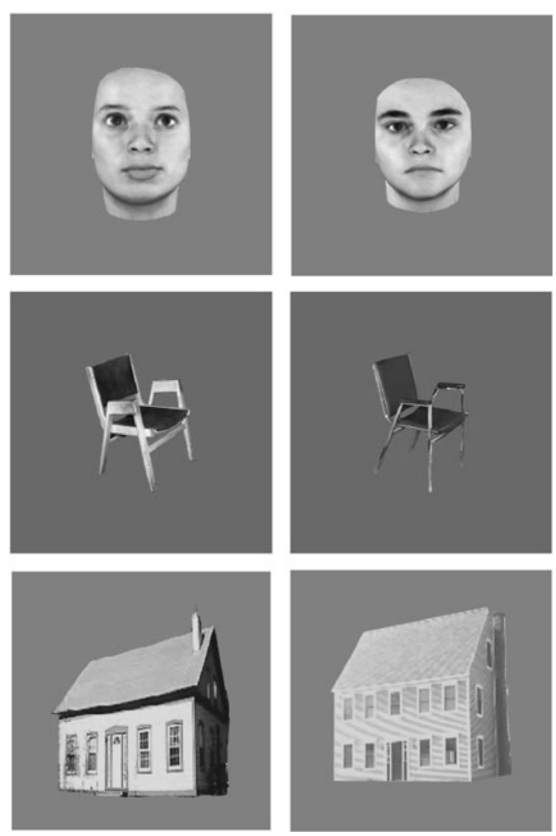

Figure 1. An example of the images used in Experiments 1 and 2.

faces and 40 houses were randomly chosen from the corresponding set and used as targets during the study stage. Half of the target faces were males, and half were females.

Presentation order of the chair and house blocks was counterbalanced across participants. Prior to the experiment, the participants were shown one practice block with three studied face targets and three test trials. A 15-min break was given between blocks.

Results and Discussion

Percentages of correct responses are presented in Figure 2. Because block (chair or house) had no theoretical significance, analyses were collapsed over block. A 2 × 2 × 2 mixed design ANOVA with age group (OAs or YAs) as an independent measures variable and image type (faces or objects) and orientation (upright or inverted) as repeated measures variables was performed on the average percentages of correct responses. The main effects of age group [$F(1,26) = 5.11$, $MS_e = 211.57$, $p = .03$], image type [$F(1,26) = 20.53$, $MS_e = 141.31$, $p < .01$], and orientation [$F(1,26) = 66.81$, $MS_e = 59.98$, $p < .01$] were significant. The image type × orientation interaction was also significant [$F(1,26) = 30.59$, $MS_e = 62.84$, $p < .01$]. No other effects were significant.

The presence or absence of an FIE was examined for the OAs and YAs separately, using contrast analyses. For the OAs, face recognition was significantly impaired by inversion [$F(1,26) = 32.79$, $MS_e = 84.16$, $p < .01$], but object recognition was not [$F(1,26) = 1.15$, $MS_e = 84.16$, $p = .29$]. Similarly, for the YAs, face recognition was significantly impaired by inversion [$F(1,26) = 35.44.03$, $MS_e = 84.16$, $p < .01$], but object recognition was not [$F(1,26) = 1.11$, $MS_e = 84.16$, $p = .30$]. Our results replicate the FIE in both OAs and YAs, suggesting that encoding of second-order relations is not impaired in OAs.

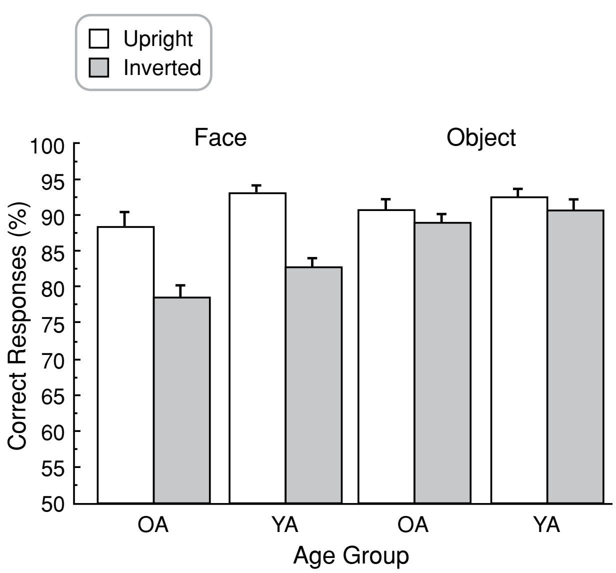

Figure 2. Average recognition accuracy (percentages of correct responses) obtained in Experiment 1 for upright and inverted faces and objects for younger adults (YA) and older adults (OA) (14 participants/group). Error bars represent ±1 *SE*.

Differences between OAs and YAs in their ability to recognize upright faces and objects were examined separately, using contrast analyses. Recognition of upright faces was superior in YAs than in OAs [$F(1,26) = 7.18$, $MS_e = 62.84$, $p = .01$]. In contrast, there was no difference between the two groups for recognition of upright objects [$F(1,26) = 1.01$, $p = .32$]. A post hoc t test revealed that this finding is not attributable to a difference in task difficulty, because recognition of upright faces did not differ from recognition of upright objects ($t < 1$, $MS_e = 97.27$). Therefore, our results suggest that differences between OAs and YAs are limited to face recognition and that age differences do affect some of the mechanisms that are specialized for face recognition, but not those involved in producing the FIE.

EXPERIMENT 2

The recognition task employed in Experiment 1 required retrieval of representations stored in long-term memory, because several minutes elapsed between the study phase and the recognition phase. In Experiment 2, we examined whether the results obtained in Experiment 1 could be replicated using a working memory task. The FIE was assessed in OAs and YAs, using a rapid sequential matching task that did not require long-term memorization of the faces presented during the study stage. In this task, encoded representations likely remain in working memory, because the delay between study and recognition is too short to allow for transfer into long-term memory.

Long-term and working memory tasks have been shown to yield inconsistent age effects (e.g., Connor, 2001; Park et al., 1996; Yokota et al., 2000). These discrepancies likely arise because different tasks tap into different types of memory, not all of which are equally affected by aging. For example, long-term recognition tasks rely more on episodic recognition memory, a type of memory that has been shown to consistently deteriorate with aging (Craik & Jennings, 1992). Working memory tasks involve temporary storage and manipulation of episodic information (Baddeley, 2002). Age differences are less pronounced for working memory tasks that are similar to those employed in Experiment 2, where short-term storage of information is required without any further manipulation (e.g., Grégoire & Van der Linden, 1997). Experiment 2 therefore allowed us to examine whether a working memory task would show a pattern of age differences for the recognition of faces and objects and for the encoding of second-order relations similar to that in Experiment 1.

Method

Participants. Fifteen OAs (mean age, 71 years; range, 66–78 years) were recruited from the Optometry Clinic at the Université de Montréal. None of these participants had been tested in Experiment 1. The MMSE was administered on a different day than the experiment and only to those participants who could be contacted and who were willing to come back to the laboratory. Eleven out of 15 participants were tested on the MMSE. The mean score for this group was 28 ($SD = 1.30$). Fifteen YAs (mean age, 23 years; range, 21–27 years) were recruited from ads posted in several university buildings. The participants gave informed consent after the procedure had been explained to them. Visual acuity criteria, use of +1.00 lenses for OAs, and self-reported medical status for the participants were as described in Experiment 1.

Apparatus and Stimuli. The apparatus and stimuli were the same as those in Experiment 1.

Procedure. A 2AFC sequential matching procedure was used in Experiment 2. One trial consisted of the presentation of one target image at the center of the monitor for 20 msec during the study stage, followed by a 2-sec mask and then by the presentation of two test images. Test images were presented to the left and right of fixation. The participants were given as much time as needed to decide which of the two test images matched the studied image. The experimenter (I.B.) entered the responses.

As in Experiment 1, two blocks were tested, a chair block and a house block. Each block consisted of the presentation of 80 trials. Faces were presented in half the trials, and objects in the other half. Images were presented upright in half of the trials and inverted in the other half. Image orientation was the same during study and testing. As in Experiment 1, for the chair block, 40 faces and 40 chairs were chosen from the corresponding set and used as targets. For the house block, 40 faces and 40 houses were chosen from the corresponding set and used as targets.

The order of presentation of the chair and house blocks was counterbalanced across participants. Prior to the experiment, the participants were tested on three practice trials. A 15-min break was given between the two blocks.

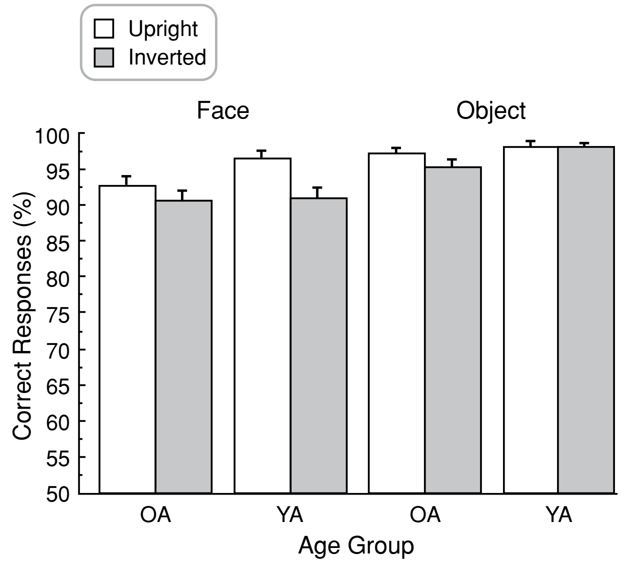

Figure 3. Average recognition accuracy (percentages of correct responses) obtained in Experiment 2 for upright and inverted faces and objects for younger adults (YA) and older adults (OA) (15 participants/group). Error bars represent ±1 *SE*.

Results and Discussion

Percentages of correct responses collapsed over block are presented in Figure 3. A 2 × 2 × 2 mixed design ANOVA with age group (OAs or YAs) as the independent measures variable and image type (faces or objects) and orientation (upright or inverted) as repeated measures variables was performed on the average percent correct. The main effects of age group [$F(1,28) = 5.17$, $MS_e = 197.44$, $p = .03$], image type [$F(1,28) = 105.07$, $MS_e = 32.49$, $p < .01$], and orientation [$F(1,28) = 50.46$, $MS_e = 24.48$. $p < .01$] were significant. The image type × orientation interaction was also significant [$F(1,26) = 23.89$, $MS_e = 24.50$, $p < .01$]. No other effects were significant.

The presence or absence of an FIE was examined in OAs and YAs separately, using contrast analyses. For OAs, face recognition [$F(1,28) = 33.75$, $MS_e = 24.50$, $p < .01$] and object recognition [$F(1,28) = 4.50$, $MS_e = 24.50$, $p = .04$] were significantly impaired by inversion. However, as predicted by the FIE, the effect of inversion was more pronounced for faces than for objects. For YAs, face recognition was significantly impaired by inversion [$F(1,28) = 38.17$, $MS_e = 24.50$, $p < .01$], but object recognition was not ($F < 1$, $MS_e = 24.50$).

These results replicate the FIE, with face recognition being more significantly affected by inversion than was object recognition in both OAs and YAs. This finding is consistent with the results of Experiment 1 and provides additional evidence that the mechanisms involved in the FIE are not influenced by age differences. This suggests that encoding of second-order relations is not impaired in OAs.

Differences between OAs and YAs in their ability to recognize upright faces and objects were examined separately, using contrast analyses. Recognition of upright faces was superior in YAs than in OAs [$F(1,28) = 18.78$, $MS_e = 24.50$, $p < .01$]. In contrast, there was no difference between the two groups for recognition of upright objects [$F(1,28) = 1.67$, $p = .20$]. However, this finding could be due to a ceiling effect and/or to differences in task difficulty. A post hoc t test revealed that recognition of upright objects was 6% higher than that of upright faces [$t(27) = 25.86$, $MS_e = 23.00$, $p < .01$]. Because the nonsignificant difference between OAs and YAs in object recognition found in Experiment 1 was not limited by these possible confounds, we conclude that age differences are more reliable for face recognition than for objects.

Although the working memory task used in Experiment 2 proved much easier than the long-term memory task used in Experiment 1 for both groups, comparable age-related face recognition deficits were observed in both experiments. Our results are consistent with those of other studies in showing that age differences in face recognition generalize across experimental methods (see the review in Searcy et al., 1999).

Experiments 1 and 2 were conducted to examine whether (1) processing of second-order relations, as measured by the FIE, is impaired in OAs and (2) age-associated recognition deficits are present for both faces and nonface objects when equivalent within-category tasks are used. Our findings are consistent in showing that the FIE is comparable in OAs and YAs, suggesting that encoding of second-order relations is not impaired in OAs. Our results also show that whereas OAs performed more poorly than YAs in face recognition, there was no significant difference between the two groups in object recognition. It should be noted that the small sample sizes used in Experiments 1 and 2 might not have yielded enough power to detect a small difference in performance between OAs and YAs for object recognition. Furthermore, a ceiling effect may have obstructed potential age differences in Experiment 2. Nonetheless, our results indicate that differences between OAs and YAs are more reliable for face recognition than for object recognition. This finding suggests that age-related impairments in face recognition do not generalize to within-category recognition of other objects. It also suggests that aging affects some of the mechanisms that are specialized for face recognition, but not those that are involved in the FIE.

EXPERIMENT 3

In Experiment 3, we used the composite effect (Young et al., 1987) to further examine whether face-specific encoding mechanisms are impaired in OAs. Composite stimuli are created by dividing two familiar faces along the horizontal line of the nose and by aligning the two halves one on top of the other (see Figure 4). Comparable noncomposite stimuli can be created by misaligning the two halves. A composite effect is observed when recognition of composites is inferior to that of noncomposites in the upright, but not the inverted, orientation (Young et al., 1987). The effect arises because the halves from the composite appear fused together to produce the illusion of a novel face. Because the holistic representation formed by this new face does not match the stored representations from prior viewing of either face, recognition of each part of the composite becomes difficult. Recognition of each part of noncomposites is significantly better than that of composites, since the two halves do not create a new holisitic representation. Superior recognition of noncomposites is eliminated by inversion, suggesting that the difficulty in recognizing upright composites arises from upright faces being automatically analyzed in a holistic fashion. In Experiment 3, we tested OAs and YAs on recognition of parts of upright and inverted composites and noncomposites, to examine whether processing of holistic information is affected by age differences.

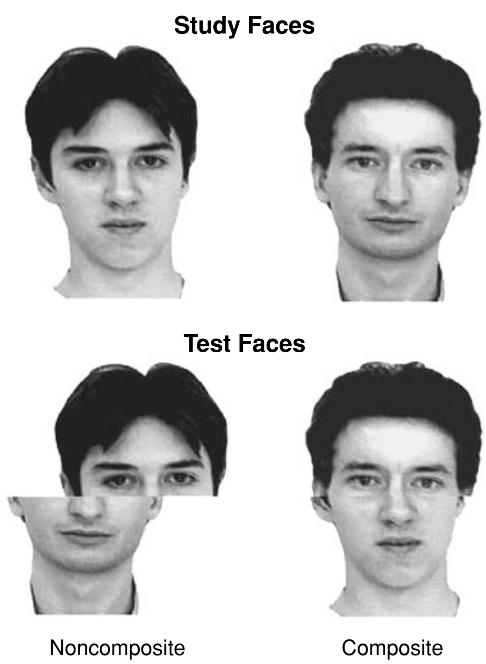

Figure 4. An example of the study (top row) and test (bottom row) stimuli employed in Experiment 3. The noncomposite stimulus was created using the top half from the face shown on the top left and the bottom half from the face shown on the top right. The composite stimulus was created using the top half from the face shown on the top right and the bottom half from the face shown on the top left.

Method

Participants. Sixteen OAs (mean age, 70 years; range, 66–84 years) were recruited from the Optometry Clinic at the Université de Montréal. Three of these participants had taken part in Experiment 1 more than 6 months prior to participating in Experiment 3. Mental status was evaluated in all the participants, using the MMSE ($M = 28.4$, $SD = 1.15$). The MMSE was administered to all the participants prior to participation in the experiment. The participants obtained a mean score of 28.4 ($SD = 1.15$). Sixteen YAs (mean age, 24 years; range, 18–28 years) were recruited, using an ad in a community newspaper. The participants gave informed consent after the procedure was explained to them. Visual acuity criteria, use of $+1.00$ lenses for OAs, and self-reported medical status for the participants were as described in Experiment 1.

Apparatus and Stimuli. The apparatus was the same as that in Experiment 1. The stimuli used for this experiment were taken from Boutet, Gentes-Hawn, and Chaudhuri (2002). Forty-eight digitized photographs of male faces were obtained from a face database at the University of Essex. The original full-color face images were converted to a 256 gray-level format. The face images were 180×200 pixels (subtending 3.72×4.00 deg of arc at a viewing distance of 1 m). The composite stimuli shown at testing were created by pairing each face with another face on the basis of physical similarity of their contour. All the faces were divided into a top and bottom segment by slicing them just below the eyes. Composites were constructed by positioning the top segment of one face on top of the bottom segment of the other face and vice versa. Noncomposites were created by positioning the nose of the bottom segment of one face next to either the right (Type A) or left ear (Type B) of the top segment of the other face and vice versa. All the stimuli were surrounded by a gray window that matched the background.

For each participant, 12 face pairs were randomly chosen among the 24 available pairs and used as targets during the study stage; 12 other face pairs were randomly chosen and used as distractors for testing. Targets in the recognition test were made up of two halves from two different faces that had been shown during the study stage; distractors were made up of two halves from two different faces that were not shown during the study stage.

Procedure. This experiment employed a blocked recognition paradigm with four blocks of study/test stages. For half the participants, the two first blocks were used for the upright condition, and the two last blocks for the inverted condition. The reverse was true for the other half. Each study stage consisted of the presentation of six target faces for 7 sec in the upright blocks and 8 sec in the inverted blocks. Presentation of each target was separated by a 400-msec interstimulus blank screen. Each test stage consisted of the presentation of six target stimuli composed of studied faces and six distractor stimuli composed of new faces. Half of the test stimuli were composites, and the other half were noncomposites. Presentation order of targets and distractors and of composites and noncomposites was randomized. Upon presentation of each test stimulus, the participants were instructed to take as much time as necessary to determine whether or not they had seen the top half of each stimulus in the previous study stage (*old* or *new*). The participants gave a verbal response and the experimenter (I.B.) pressed the appropriate key on the keyboard. A blank screen with a black fixation point was shown for 1 sec between stimulus presentations.

Results and Discussion

Because OAs may show a different response criterion than do YAs (see, e.g., Yonelinas, 2002), we used sensitivity (d') and bias (C) measures derived from signal detection theory to analyze our results (Macmillan & Creelman, 1991). For each age group, d' performance is presented in Figure 5. The values for C are presented in Table 1, which also includes the proportion of hits and false alarms.

***d′* analysis**. We analyzed d' values by using a 2 × 2 × 2 mixed design ANOVA with age group (OAs or YAs) as the independent measures variable and orientation (upright or inverted) and condition (composites or noncomposites) as the repeated measures variable. The main effects of age group [$F(1,30) = 9.49$, $MS_e = 0.73$, $p < .01$] and orientation [$F(1,30) = 5.72$, $MS_e = 0.45$, $p = .02$] were significant. The orientation × condition interaction was significant [$F(1,30) = 7.41$, $MS_e = 0.32$, $p = .01$]. No other effects were significant.

Contrast analyses were performed to confirm the presence or absence of a composite effect for each group separately. For YAs, recognition of upright noncomposites was superior to that of upright composites [$F(1,30) = 7.18$, $MS_e = 0.32$, $p < .01$]. In contrast, there was no significant difference between recognition of composites and noncomposites in the inverted condition [$F(1,30) = 2.39$, $MS_e = 0.32$, $p = .13$]. This result reflects the composite effect, whereby recognition of composites is inferior to that of noncomposites in the upright, but not the inverted, orientation (Young et al., 1987). For OAs, recognition of composites did not differ from that of noncomposites in both the upright ($F < 1$, $MS_e = 0.32$) and the inverted [$F(1,30) = 2.72$, $MS_e = 0.32$, $p = .10$] orientations. That is, the older group did not display a statistically significant composite effect.

***C* analysis**. C values were analyzed using a 2 × 2 × 2 mixed design ANOVA with age group (OAs or YAs) as the independent measures variable and orientation (upright or inverted) and condition (composites or noncomposites) as the repeated measures variables. The main effect of interest, age group, was significant [$F(1,30) = 6.03$, $MS_e = 0.11$, $p = .02$]. No other effects were significant. Overall, YAs obtained an average C value of −.08, and OAs an average C value of −0.26, suggesting that the OAs adopted a more liberal response bias than did the YAs. The more liberal bias can also be seen in the hits and false alarms. OAs and YAs had similar hit rates but higher false alarm rates.

Consistent with the results obtained in Experiments 1 and 2, we found that recognition performance was lower overall for OAs, as indicated by the main effect of age group for the d' data. These results further indicate that face processing is impaired in healthy individuals 65 years of age and over. Our results also indicate that OAs are more biased for judging new test stimuli as being old than are YAs. Searcy et al. (1999) reviewed 12 studies that examined recognition memory for unfamiliar faces in OAs and YAs. They concluded that whereas hit rates are generally similar for OAs and YAs, false alarm rates for YAs are consistently lower than those for OAs. Our results are in agreement with this conclusion.

With respect to the composite effect, a different pattern of results was observed for OAs and YAs. YAs showed the standard composite effect, with recognition of parts of composites being inferior to that of noncomposites in the upright, but not the inverted, condition. In contrast, there was no significant difference between recognition of composites and noncomposites in both the upright and the inverted conditions in OAs. On one hand, lack of power may have prevented us from detecting a difference between upright composites and noncomposites in OAs. On the other hand, it may be that the OAs did not display a composite effect because they did not encode faces in a holistic fashion. Whether holistic encoding is impaired in OAs was further examined in Experiment 4.

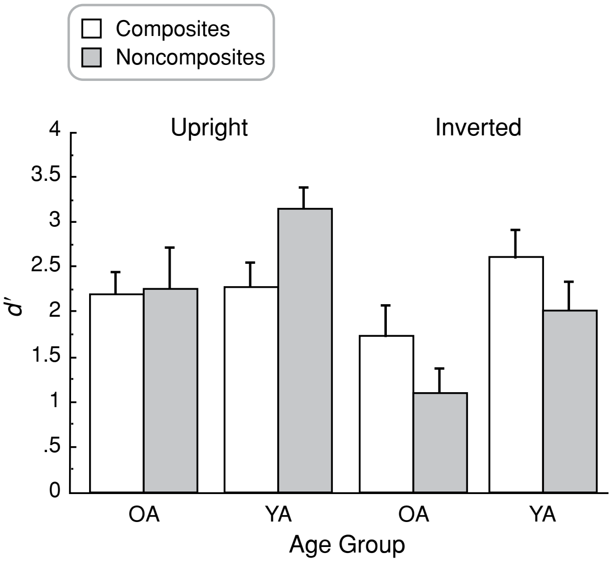

Figure 5. Average sensitivity (*d′*) obtained in Experiment 3 for recognition of composites and noncomposites in the upright and inverted conditions for younger adults (YA) and older adults (OA) (16 participants/group). Error bars represent ±1 *SE*.

Table 1
***C* Values and Percentages of Hits and False Alarms (FAs) Obtained in Experiment 3**

	Younger Adults						Older Adults					
	Hits		FAs		*C*		Hits		FAs		*C*	
Stimuli	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Upright composites	77.08	14.75	16.67	13.61	0.02	0.23	81.25	21.84	26.04	21.92	−0.15	0.45
Upright noncomposites	92.71	8.56	12.50	14.27	−0.17	0.20	86.46	22.95	33.33	29.81	−0.33	0.51
Inverted composites	87.50	14.26	21.87	16.91	−0.17	0.24	80.21	18.47	33.33	21.94	−0.23	0.35
Inverted noncomposites	77.09	18.12	22.92	15.96	−0.02	0.29	78.12	15.76	44.79	22.54	−0.35	0.37

EXPERIMENT 4

In Experiment 4, we employed the whole/part advantage to examine whether holistic encoding is impaired in OAs (de Gelder & Rouw, 2000; Tanaka & Farah, 1993; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). YAs and OAs were shown a studied face, followed by a test window containing either a target and a distractor face or a target and a distractor face part. The stimuli were either upright or inverted. The whole/part advantage is that recognition of full-face targets is superior to that of isolated-parts targets in the upright, but not in the inverted, orientation. This effect indicates that facial features are not represented in isolation but, rather, as part of a unitary representation of the face as a whole—hence, the term *holistic* representations (Tanaka & Farah, 1993). Scrambled faces, inverted faces, and houses do not show this whole/part advantage, suggesting that these types of stimuli are, instead, recognized on the basis of isolated features.

Method

Participants. Sixteen OAs participated in Experiment 4. All had already participated in Experiment 3 less than 1 week before participating in Experiment 4. Sixteen young participants (mean age, 23 years; range, 18–31 years) were recruited from an ad in a community newspaper. The participants gave informed consent after the procedure had been explained to them. Visual acuity criteria, use of +1.00 lenses for OAs, and self-reported medical status for the participants were as described in Experiment 1.

Apparatus and Stimuli. The apparatus was the same as that in Experiment 1. Ten faces were created using the Adobe Photoshop 6.0 software in the following fashion. Fifty original grayscale photographs of faces taken from those used in the house block in Experiment 1 were cropped so that their eyes, nose, and mouth could be removed from their external features. Using this set of internal and external features, 10 faces were created, using different external feature sets and internal features from the original set. Features used to create a given face were always from different original faces in order to ensure that all the faces appeared equally realistic. The size of the external features was averaged across baseline faces so that all faces were 7.5 cm in width and 11.5 cm in height (subtending 4.29×6.56 deg of arc at a viewing distance of 100 cm). For the full-face condition, each target face was matched with three distractors. Distractors were created by removing the eyes, the nose, or the mouth from each target face and replacing them with a distractor feature. The eyes, nose, and mouth of corresponding target and distractor faces were shown in isolation for the isolated-parts condition (see Figure 6).

Procedure. A sequential matching paradigm was used. For each trial, one target face was shown for 1.75 sec. Presentation of the target was followed by a gray noise mask for 400 msec and then by a test window. For the full-face trials, the test window displayed the target face and a distractor face. For isolated-parts trials, the test window displayed one target feature (eyes, nose, or mouth from the target face) and one distractor feature. Target and distractor stimuli were shown on each side of fixation, with their position being counterbalanced across trials. A word cue appeared at the top of each test window to inform the participants of which feature they had to identify. The participants were given as much time as necessary to identify the feature corresponding to the previously presented target face. The participants gave a verbal response (left or right) and the experimenter (I.B.) pressed the appropriate key on the keyboard.

Two blocks of 60 trials were employed. One block was for the upright condition, and one block for the inverted condition. The testing order of the blocks was counterbalanced across participants. Out of the 60 trials, 30 tested the full-face condition, and 30 the isolated-parts condition. For each condition, each of the 10 target faces was shown three times during the study stage, followed by the target face/part and its respective distractor created by changing the eyes, nose, or mouth. A sheet of paper was used to explain the task to the participants before testing. A break of 10 min was allocated between the two blocks.

Results and Discussion

Percentages of correct responses are presented in Figure 7. A $2 \times 2 \times 2$ mixed design ANOVA with age group (YAs or OAs) as the independent measures variable and orientation (upright or inverted) and test type (full face or isolated part) as the repeated measures variables was performed on the average percentage of correct responses

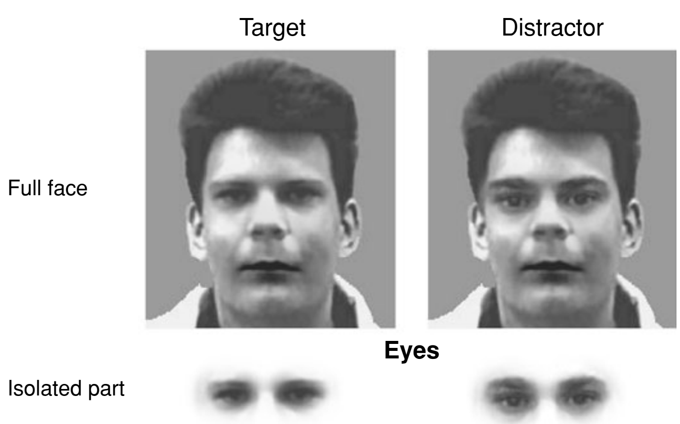

Figure 6. An example of the images employed in Experiment 4. A full-face target (top row, left face) was shown during the study stage, followed by either two full faces (top row) or two face parts (bottom row). The participants had to identify the cued target feature (eyes, in this example).

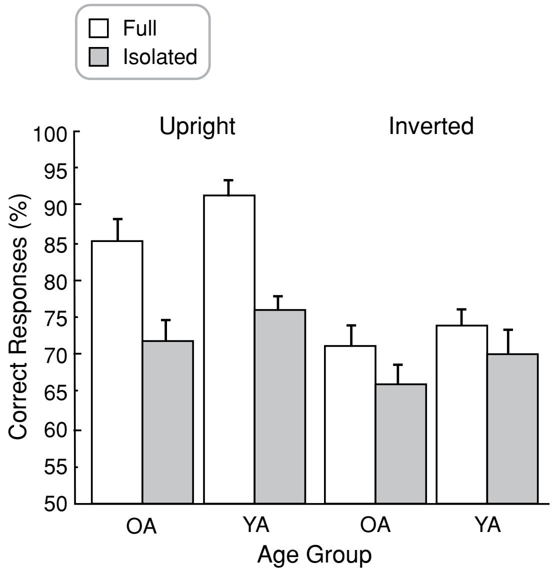

Figure 7. Average recognition accuracy (percentages of correct responses) of cued features presented in full faces (full) or in isolation (isolated) for the upright and inverted conditions for younger adults (YA) and older adults (OA) (16 participants/group). Error bars represent ±1 *SE*.

obtained across participants. The main effects of age group [$F(1,30) = 4.80$, $MS_e = 184.57$, $p = .04$], orientation [$F(1,30) = 64.42$, $MS_e = 62.30$, $p < .01$], and test type [$F(1,30) = 64.15$, $MS_e = 52.52$, $p < .01$] were significant. The orientation × test type interaction was also significant [$F(1,30) = 16.72$, $MS_e = 44.91$, $p = .04$]. No other effects were significant.

The presence or absence of a whole/part advantage was examined separately in OAs and YAs, using contrast analyses. For OAs, recognition of full-face targets was superior to that of isolated-parts targets in the upright [$F(1,30) = 33.67$, $MS_e = 44.91$, $p < .01$] and the inverted [$F(1,30) = 4.83$, $MS_e = 44.91$, $p = .04$] conditions. Similarly, for YAs, recognition of full-face targets was superior to that of isolated parts in the upright [$F(1,30) = 48.25$, $MS_e = 44.91$, $p < .01$] and the inverted [$F(1,30) = 5.64$, $MS_e = 44.91$, $p = .03$] conditions. Note that although full-face targets were better recognized than isolated-part targets in both the upright and the inverted orientations, the difference between these two conditions was more pronounced for the upright than for the inverted condition, as predicted by the whole/part advantage (see de Gelder & Rouw, 2000, for a similar finding).

Consistent with the results obtained in the other experiments conducted, we found a significant main effect of age group in further support of impaired face processing in the elderly. More important, we found that both YAs and OAs display the whole/part advantage. This effect is interpreted as showing that facial features are not represented in isolation but, rather, as part of a unitary representation of the face as a whole (Tanaka & Farah, 1993). Therefore, holistic encoding appears to be intact in OAs.

GENERAL DISCUSSION

We conducted four experiments to examine whether (1) recognition deficits in the elderly are unique to faces or also apply to other within-category recognition tasks and (2) processing of second-order relations and holistic information is impaired in OAs. With respect to the first question, our results suggest that age differences are more reliable for face recognition than for object recognition, even when equivalent within-category tasks are used. Therefore, we interpret our results as evidence for a face-specific recognition deficit in OAs.

With respect to the second question, the results of Experiments 1 and 2 indicate that OAs and YAs displayed a similar pattern of results for the FIE, suggesting that encoding of second-order relations is intact in OAs. Mixed results were obtained in tests of holistic encoding. In Experiment 3, YAs, but not OAs, displayed the pattern of results predicted by the composite effect. In Experiment 4, both OAs and YAs displayed the pattern of results predicted by the whole/part advantage. This discrepancy between OAs displaying a whole/part advantage but not a composite effect may be attributable to a lack of power to detect the composite effect. A relatively small number of participants were tested in Experiment 3, and only six trials were used to test each condition. Furthermore, there was a trend for a composite effect in OAs (see Table 1). These limitations, taken together with the finding that OAs displayed a whole/part advantage, suggest that holistic encoding may be intact in OAs.

Our results suggest that aging affects some of the mechanisms specialized for face recognition, but not those related to processing second-order relations and holistic information. Hence, any hypothesis that would seek to explain our results in their entirety would need to specify a mechanism that is impaired in OAs, that affects face recognition more heavily than it does within-category object recognition, and that is not related to second-order relations and holistic information. The problem is that studies aimed at deciphering differences between face and object recognition have largely focused on second-order relations and holistic information.

Expertise is another variable associated with a difference between faces and objects (e.g., Carey & Diamond, 1994; Gauthier, Williams, Tarr, & Tanaka, 1998) that may partly account for face recognition deficits in OAs. It may actually be the life-long experience that OAs have with faces that makes them more difficult to recognize. Several face and object recognition models are based on the idea that images are encoded as points in a multidimensional space (e.g., Edelman, 1995; Wilson, Loffler, & Wilkinson, 2002) or as variations from a face prototype or face norm (e.g., Rhodes, 1995; Valentine, 1991). According to these models, similar exemplars are difficult to discriminate because their representations are more likely to get confused in memory. Face stimuli may elicit more confusion errors in OAs because the quantity of face images in memory increases with aging, which makes it more likely that a new face will partially match a stored representation (Bartlett et al., 1991; Chaby et al., 2001). If this hypothesis is correct, false alarm rates should be more pronounced for faces than for nonface objects. In Experiment 3, OAs showed greater false alarm rates than did YAs for recognition of new composite and noncomposite faces. Higher false alarm rates in OAs have also been reported elsewhere (see the review in Searcy et al., 1999). Future studies should compare false alarm rates for faces and objects in OAs and YAs in order to formally explore this hypothesis.

Another possible explanation for the data is that OAs have greater difficulty recognizing faces than recognizing objects because face recognition is a more complex process. Complexity, in this context, may be defined by the number of neural operations required before a stimulus can be perceived (Faubert, 2002). Within this framework, faces can be construed as more complex than objects because they recruit more extensive neural circuitry for perception and recognition (Blonder et al., 2004; Haxby, Hoffman, & Gobbini, 2000; Puce, Allison, Asgari, Gore, & McCarthy, 1996). For example, faces, but not objects, possess a wealth of information that facilitates social communication. Faces are known to activate regions involved in the recognition of identity (e.g., the fusiform gyrus), as well as those involved in processing emotions (e.g., the amygdala; Haxby et al., 2000). Faubert has suggested that the changes in neuronal circuitry associated with aging may be detectable only with more complex stimuli that saturate access to alternative or compensatory neural routes. Grady (2002) has provided supporting evidence for this hypothesis. Her findings suggested that impaired face recognition in OAs may be due to decreased activation in regions responsible for face encoding, as well as lack of activation in other areas that could potentially compensate for the age-related dysfunction in encoding networks. Imaging studies comparing within-category recognition of faces and objects in OAs and YAs could shed light on this compelling idea.

Our results highlight the ambiguity inherent to the distinction between processing of isolated features, first-order relations, second-order relations, and holistic representations. As such, attempts to manipulate the different kinds of information involved in face recognition independently may never be entirely successful. Manipulations that alter an isolated feature are bound to affect holistic representations, and vice versa. Furthermore, it is unclear whether manipulated images that no longer resemble face stimuli actually trigger face-specific processes. Finally, whether participants rely on features or second-order relations to recognize and discriminate faces may depend on the task at hand (Hole, 1994). We have attempted to address these limitations by using a variety of measures to examine the encoding of second-order relations and holistic information.

To conclude, our results indicate that differences between OAs and YAs are more reliable for face recognition than for object recognition, even when an equivalent within-category task is used. Our findings also suggest that processing of second-order relations and holistic information is intact in OAs. Further research is necessary to determine the factors that are responsible for recognition impairments in OAs. Findings from these studies could inform procedures used in the treatment of older witnesses to crime.

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NOTE

1. It may be argued that the results we obtained are not part of healthy aging but, rather, the result of preclinical dementia. Memory and recognition deficits are present in the early stages of Alzheimer's disease and vascular dementia (e.g., Fahlander, Wahlin, Almkvist, & Bäckman, 2002). Across all four experiments, the MMSE was administered to 80% of our older participants. They obtained an average score of 28 (SD = 1.5), which is above the 26-point cutoff for dementia. Hence, we are confident that our groups formed a representative sample for studying healthy aging. Another potential difference is the education level of our older participants. Equating education across younger and older groups is often difficult because education levels are generally lower in the geriatric population. Nonetheless, we made an effort to recruit older participants with university degrees, as well as younger participants who had not finished high school. The average number of years of education for the YAs was 13.22 (SD = 1.13). For the OAs, the average was 12.75 (SD = 1.55). Hence, it is unlikely that level of education was responsible for the differences we observed.

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