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Research report

A new selective developmental deficit: Impaired object recognition with normal face recognition

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A B S T R A C T

Introduction: Studies of developmental deficits in face recognition, or developmental prosopagnosia, have shown that individuals who have not suffered brain damage can show face recognition impairments coupled with normal object recognition (Duchaine and Nakayama, 2005; Duchaine et al., 2006; Nunn et al., 2001). However, no developmental cases with the opposite dissociation – normal face recognition with impaired object recognition – have been reported. The existence of a case of non-face developmental visual agnosia would indicate that the development of normal face recognition mechanisms does not rely on the development of normal object recognition mechanisms.

Methods: To see whether a developmental variant of non-face visual object agnosia exists, we conducted a series of web-based object and face recognition tests to screen for individuals showing object recognition memory impairments but not face recognition impairments. Through this screening process, we identified AW, an otherwise normal 19-year-old female, who was then tested in the lab on face and object recognition tests.

Results: AW's performance was impaired in within-class visual recognition memory across six different visual categories (guns, horses, scenes, tools, doors, and cars). In contrast, she scored normally on seven tests of face recognition, tests of memory for two other object categories (houses and glasses), and tests of recall memory for visual shapes. Testing confirmed that her impairment was not related to a general deficit in lower-level perception, object perception, basic-level recognition, or memory.

Discussion: AW's results provide the first neuropsychological evidence that recognition memory for non-face visual object categories can be selectively impaired in individuals without brain damage or other memory impairment. These results indicate that the development of recognition memory for faces does not depend on intact object recognition memory and provide further evidence for category-specific dissociations in visual recognition.

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1. Introduction

Faces are a rich source of social information, and some have suggested that face-specific mechanisms have been selected over the course of evolution to support face processing (Farah, 2000; Pinker, 1997). The existence of specialized face processing mechanisms has been supported by studies using a number of techniques. Neuroimaging and neurophysiological experiments have identified cortical regions that preferentially respond to faces (Gauthier et al., 2000; Kanwisher et al., 1997; Moeller et al., 2008) and transcranial magnetic stimulation is capable of selectively disrupting face processing (Pitcher et al., 2009). Research suggests that face processing might also differ from object processing in terms of the types of representations and/or the neural systems. Behavioral evidence indicates that face perception and recognition involve holistic representations of facial information (Robbins and McKone, 2007; Tanaka and Farah, 1993; Young et al., 1987) whereas object processing relies more on parts-based information (Biederman, 1987). Face processing may also depend more heavily than object processing on within-category representations (Damasio, 1990). Face processing may further differ from object processing in its relationship to systems specialized for socially relevant information (Brothers, 1990; Haxby et al., 2002).

Studies of individuals with acquired visual recognition deficits also support the distinction between face recognition and object recognition. A number of acquired prosopagnosics with preserved recognition for other object classes have been reported (Henke et al., 1998; Riddoch et al., 2008; Rossion et al., 2003), including cases in which recognition was intact for within-category objects of expertise (McNeil and Warrington, 1993; Sergent and Signoret, 1992). The opposite dissociation has also been described, in which significant object recognition impairments are found alongside normal or relatively spared face recognition abilities (Feinberg et al., 1994; McMullen et al., 2000; Moscovitch et al., 1997). The most well documented example of selective acquired object agnosia is Mr. C.K., who has severe impairments in word recognition and basic-level object identification (Moscovitch et al., 1997). Although Mr. C.K. had difficulty identifying everyday items like the food items on his plate, he performed completely normal on tests involving upright faces. Most work investigating dissociations involving faces has focused on perceptual processing and neural areas in the visual system, but researchers investigating medial temporal lobe memory systems have also reported cases of memory deficits where face memory is preserved despite deficits in topographical memory (Bird et al., 2008; Carlesimo et al., 2001; Incisa della Rocchetta et al., 1996; Maguire et al., 1996; Whiteley and Warrington, 1978) and verbal memory (Bird et al., 2007). These studies indicate that face processing is dissociable from the processing of other types of visual information in perception and in memory.

Developmental prosopagnosia (DP) is characterized by impairments in face recognition that are not due to lower-level deficits or acquired brain damage (McConachie, 1976). Many individuals with DP have deficits with both face and object processing (Behrmann et al., 2005; Duchaine et al., 2007b; Duchaine and Nakayama, 2005), but some exhibit face-specific deficits with no evidence of impairment in matched tests of object recognition or other types of visual recognition (Bentin et al., 1999; Duchaine and Nakayama, 2005; Duchaine et al., 2006; Nunn et al., 2001). Such cases suggest that the development of mechanisms for face recognition and for object recognition involve different processes. However, no developmental cases of selective object recognition deficits have been reported. The absence of documented selective developmental object deficits leaves it unclear whether the development of face recognition depends on the presence of normal object recognition. For instance, specializations for faces may only develop after a period in which face recognition is handled by general-purpose object recognition mechanisms.

To address these questions, we identified and tested AW, an individual with a selective deficit in recognition memory for objects and scenes. Critically, AW does not show any evidence of deficits in face recognition, basic-level (between-category) deficits, or other visual recognition impairments. Her results provide the first neuropsychological evidence that the ability to remember and recognize faces can develop normally even when object recognition memory is impaired.

2. Neuropsychological assessment

AW is a left-handed, 19-year-old Welsh woman with no neurological or psychiatric history. She is currently a university student. AW is unaware of any head trauma that may have occurred during her life and examination of AW's structural magnetic resonance image (MRI) revealed no signs of neurological trauma or other apparent brain abnormalities. She has an identical (monozygotic) twin sister, SW, who does not appear to suffer from any visual recognition problems. SW is also left-handed. Although both AW and SW were born 5 weeks premature, no other reported complications were associated with their birth.

AW reports problems with recognition that extend back to childhood. She gets lost easily and frequently loses things. In fact, her tendency to lose personal items was so marked that while AW was attending a primary school of 500 students, school officials often brought lost items to her before the rest of the students, as they were frequently her belongings. She reports finding it difficult to keep track of personal possessions such as writing instruments and has a habit of accidentally taking friend's possessions. When asked if she has any difficulty identifying her car, she told us that this was not a problem as she had covered it with flower stickers so she could recognize it easily. AW reports difficulties with navigation that may be related to her visual recognition impairments. For instance, she commented that she can pass the door of a room she is reasonably familiar with several times before identifying it because she cannot distinguish it from the other doors in a hallway. When asked if she had ever noticed any difficulty with faces, she indicated that she has never had any problem recognizing people.

All participants, including normal control participants, gave informed consent prior to their participation as directed by the University College London ethics committee.

2.1. *Identification through web-based screening*

AW was identified through screening participants who did a set of publicly accessible, web-based tests of face and object recognition that we put on the internet to allow the public to test their visual recognition skills. These tests were used to screen participants for patterns of impairment consistent with a selective developmental deficit. AW scored normally on all three face recognition tests that were available (one famous face test and two tests of unfamiliar face recognition), but scored more than two standard deviations (SDs) below the mean on a test of recognition memory for cars (Table 1). We contacted her and asked her to do a few more tests that we administered privately over the internet. She was not informed why we wanted to carry out further testing with her until she had scored normally on two more face recognition tests (old/new faces 1 and 2; see Fig. 1) and displayed impairments on two additional old/new visual recognition tests (old/new guns and old/new scenes). At that point we explained why we were interested in her results and asked her to visit the lab for further testing.

2.2. *Structural MRI*

Structural MRI data were acquired to determine if AW had any visual indications of brain damage. Examination of T_1-weighted structural MR images by a radiologist revealed no evidence of brain damage or other neurological abnormalities.

2.3. *Within-category object and face recognition: old/new tests*

Following tests used for initial screening, we examined whether AW had object memory impairments with 11 tests of old/new visual recognition memory involving a variety of different categories of stimuli. These included two tests with faces and nine tests with non-face categories (cars, tools, guns, horses, scenes, two tests of houses, and two tests of glasses), seven of which have been used in published papers (Duchaine and Nakayama, 2005; Duchaine et al., 2006; Harris et al., 2005). We also present scores from AW's identical twin sister, SW, to explore the etiology of AW's impairment.

Table 1 – AW's results on initial object and face recognition tests used for screening. AW was significantly impaired on a test of old/new car recognition, but scored normally on three tests of familiar and unfamiliar face recognition.

	AW	Control mean (SD)
Initial screening tests		
Public CFMT	60/72	58.7 (8.2)
Public famous faces	.8	.88 (0.13)
Public old/new faces	.91	.88 (0.07)
Public old/new cars	.79*	.92 (0.06)

"*" indicates scores that differ significantly from the mean.

2.3.1. *Methods*

The old/new tests involved the following categories: faces (two tests), guns, cars, tools, glasses (two tests: sunglasses and eyeglasses), horses, houses (two tests), and scenes. During the first phase of each test, participants studied 10 target items presented one at a time for 3 sec each. Each target was shown twice. In the second phase, participants were presented with 50 items one at a time and indicated whether an item was a target or a non-target as quickly as possible. The 10 target items appeared twice in the test phase whereas the 30 non-targets appeared only once. All images were shown against a white background with any conspicuous ornamentation removed. Images in the guns, horses, sunglasses, and the first houses test were in color, whereas images in the faces, cars, tools, scenes, eyeglasses and second houses tests were grey-scale. The order of items was the same for all participants.

2.3.2. *Results*

Accuracy was measured using A′, an unbiased measure of discrimination varying between .5 and 1.0 in which higher scores indicate better discrimination (Macmillan and Creelman, 1991). Performance was compared with the performance of 17 control participants (nine females and eight males) with a mean age of 27.8 for nine of 11 tests (see Garrido et al., 2008a). A final pair of tests (eyeglasses and houses) was created and administered after AW's initial results were compiled, and AW's performance on these tests is compared with the performance of a separate control group, comprised 10 participants (eight females and two males) with a mean age of 24. All data from the old/new recognition tests were analyzed using *t*-tests adapted for analysis of single case studies (Crawford and Howell, 1998).

2.3.2.1. Old/new face recognition. AW scored within the normal range on both of the old/new face recognition tests that we administered (see Fig. 1) (faces 1: $t = -.97$, $p = .17$; faces 2: $t = -.49$, $p = .2$).

2.3.2.2. Old/new object recognition. AW was significantly impaired compared to controls on four of the five old/new object categories that we tested (see Fig. 1): horses ($t = -2.53$, $p < .02$), cars ($t = -4.86$, $p < .001$), guns ($t = -5.90$, $p < .001$), and tools ($t = -3.23$, $p < .005$). Her old/new cars score is consistent with results from the screening tests, where she was also impaired in car recognition memory (see Table 1). Her A′ score with the sunglasses test was not significantly different from controls (glasses 1: $t = -.832$, $p = .21$). To determine whether her normal performance recognizing glasses was replicable, we designed and administered an additional old/new test using eyeglasses. Her performance on this test was also normal (glasses 2: $t = .45$, $p = .33$; control mean = .90, SD = .07; AW's score = .94), suggesting that her recognition of glasses is normal despite her impairments with other object categories.

2.3.2.3. Old/new place recognition. We administered two tests involving place images, one with houses and one with natural scenes. AW scored normally with houses ($t = -.49$, $p = .32$), but was significantly impaired on the scenes test ($t = -8.16$, $p < .001$). We subsequently administered a second old/new houses test, where AW also performed normally (houses 2: $t = -.53$, $p = .30$; control mean = .90, SD = .05; AW's score = .87).

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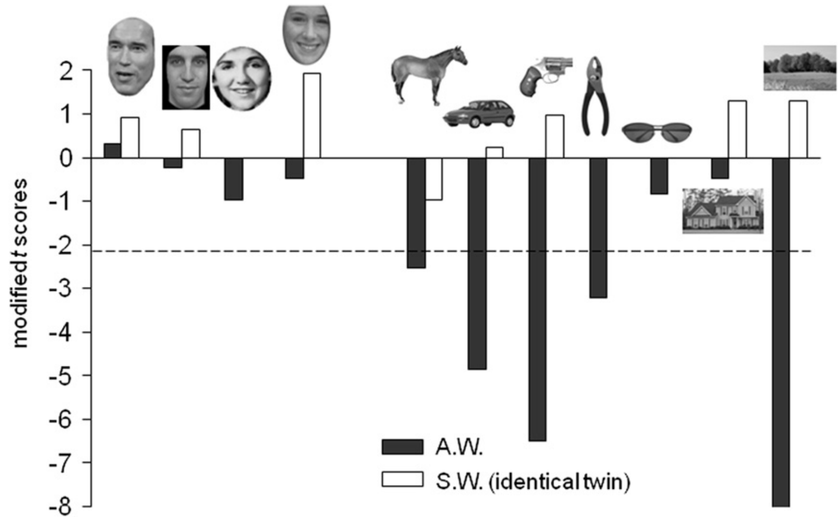

Fig. 1 – Performance of AW and SW (identical twin) on face and object recognition tests. AW's scores are shown in black and SW's scores are shown in white (where available). AW scored poorly with five of seven categories tested. SW performed normally on all tests administered. Each column shows a modified *t* score (Crawford and Howell, 1998). Modified *t* scores of 0 indicate performance that is identical to the control mean, positive values indicate performance above the control mean, and negative values indicate performance below the control mean. A dashed line has been drawn at the cut-off for impaired performance. From left to right tests shown are: famous faces, CFMT (Duchaine and Nakayama, 2006a, 2006b), old/new faces test 1, old/new faces test 2, old/new horses, old/new cars, old/new guns, old/new tools, old/new glasses 1 (sunglasses), old/new houses 1, and old/new scenes. An item from each test is displayed.

To confirm that AW's deficit in scene recognition was reproducible, we additionally administered the Warrington Topographical Recognition Memory test (Warrington, 1996). In this test, participants viewed 30 target scenes for 3 sec each, and were then asked to identify those target scenes from a test display showing a target scene alongside two distractor scenes. Control means were taken from the 'under 40' age band used in the original standardization sample for this test. One hundred and four control subjects with an average age of 30 (SD = 6.3), had a mean score of 26.1/30 (SD = 2.9) correct in this test (Warrington, 1996). AW got 20/30 items correct in this test, corresponding to a z score of −2.1, indicating significant impairment ($p < .05$).

We statistically verified a dissociation between AW's face and object recognition memory performances using the Bayesian standardized difference test developed by Crawford and Garthwaite (2007). Specifically, this test was used to determine if the difference between AW's face and object recognition scores was greater than the differences observed among control subjects. For AW and each control subject, we first created composite face recognition scores and composite object recognition scores by averaging each individual's results on the two old/new face tests and on the five old/new object tests, respectively. Scores on the screening tests (old/new faces and old/new cars, see Table 1) and on the second old/new glasses tests were not included in this analysis, as norms for these tests were based on a different group of control participants for whom scores on the other old/new tests were not available. Based on these composite scores, the Bayesian standardized difference test indicated a significant difference between AW's face and object scores as compared to the differences in scores observed among control subjects ($t = -4.93$, $p < .001$).

AW's response times were consistently within one SD of the mean, indicating that her normal scores on the face recognition tests were not due to speed-accuracy trade-offs. The notable exception to this was the scenes test, where her response times were significantly slower than the response times of normal controls ($t = -10.95$, $p < .001$).

2.3.2.4. Performance of AW's identical twin, SW. Studies of families with multiple prosopagnosics suggest that developmental deficits of visual recognition can involve heritable factors (Duchaine et al., 2007a; Grueter et al., 2007; Lee et al., 2009) and recent twin studies have demonstrated that a substantial proportion of differences in face processing ability can be traced to genetic differences (Wilmer et al., 2010; Zhu et al., 2010). We tested AW's identical twin, SW, to see if there was any evidence that AW's recognition difficulties had a heritable basis. SW's performance was normal on all old/new face, object, and place recognition tests that we administered to her: faces 2 (above average: $t = 1.94$, $p = .04$), horses ($t = -.97$, $p = .17$), cars ($t = .24$, $p = .41$), guns ($t = .97$, $p = .17$), houses ($t = 1.29$, $p = .11$), and scenes ($t = 1.29$, $p = .11$). Fig. 1 compares the scores of AW and SW on these tests and two further tests of face recognition described below.

2.4. *Further tests of face recognition*

To be certain that we did not fail to detect face recognition deficits in AW, we administered another unfamiliar face recognition test and a test of familiar face recognition.

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2.4.1. Methods

The Cambridge Face Memory test (CFMT) is a test of unfamiliar face recognition shown to be effective in identifying individuals with subtle face recognition impairments that standard tests of face recognition sometimes fail to detect (Duchaine and Nakayama, 2006b). All face images in this test were cropped so that no hair is visible. In the introduction phase of the CFMT, participants were presented with six target faces in three different orientations for 3 sec each. Immediately after studying each target face, three test items required participants to discriminate one of the study images from two other distractor faces shown in the same pose and lighting. After learning all six faces, the next 30 items required participants to identify the target faces in novel images where face posing and lighting were varied on each trial. In the final 24 items, Gaussian noise was added to novel images to increase the difficulty. There were 72 test items in total (18 study images, 30 novel images, and 24 novel images with Gaussian noise).

In the famous faces test, participants were shown 60 famous faces for 3 sec per face and asked to identify the person with their name or other uniquely identifying information.

2.4.2. Results

Our further tests of face recognition confirmed that AW has no difficulties with face recognition memory. AW's CFMT score was compared with published control scores for this test (Duchaine and Nakayama, 2006b). For 50 control participants with an average age of 20.2 (SD = 1.8), the mean score was 57.9 correct out of 72 items (SD = 7.9). AW got 56 out of 72 items correct, confirming that her unfamiliar face recognition is normal (see Fig. 1).

For the famous faces test, control participants were 8 females and 8 males with a mean age of 19.9 years (SD = 1.4), who had lived in the UK for 10 years or more. On average, control participants were able to identify 91.8% of faces that they felt they had significant exposure to (SD = 6.78%). AW indicated that she had significant exposure to all 60 people included in the test and identified 56 (93.3%) from their faces ($t = .33$, $p = .37$, Fig. 1).

AW's identical twin, SW, scored normally on both of these tests (Fig. 1).

2.5. Other memory domains

To examine whether AW's recognition deficits might result from more general memory deficits, we tested her verbal memory and visual memory using the Doors and People test (Baddeley et al., 1994) and delayed recall of the Rey–Osterrieth Complex Figure (Osterrieth, 1944; Rey, 1941).

2.5.1. Methods

The Doors and People test includes four memory subtests: a test of verbal recall (People test), a test of visual recognition (Doors test), a test of visual recall (Shapes test), and a test of verbal recognition (Names test). In the People test (the first subtest), participants viewed photographs of people labeled with their name and occupation, one at a time. Verbal recall was assessed by asking the participant to recall the name associated with each occupation, immediately and after a delay. In the Doors test, participants were asked to remember and recognize a series of door images. Visual recognition was evaluated by asking participants to identify target doors from image arrays of four doors. In the Shapes test, participants were asked to memorize four simple line drawings. Visual recall was assessed be asking participants to reproduce these drawings from memory immediately and after a delay. The line drawings depicted four different style crosses, varying in their overall shape, features located at the ends of the arms, and features located where the arms intersect. Finally, in the Names test, participants were asked to remember a series of names. Participants were then shown groups of four names, and verbal recognition was examined by asking them to indicate which of the four names was a target name. As the norms from the Doors and People visual recall subtest indicate ceiling effects in healthy populations, delayed recall of the Rey–Osterrieth Complex Figure was assessed as a further test of visual recall memory. The Rey–Osterrieth Complex Figure is a line drawing containing 18 structural elements that combine to form a single detailed geometric figure. In this test, participants were asked to memorize and copy this line drawing and then reproduce the line drawing from memory after a 35-min delay.

2.5.2. Results

AW's scores on the Doors and People test were compared to the scores of normal control subjects aged 16–31 (Baddeley et al., 1994) (Fig. 2). Her scores were above average on all three tests that did not require within-category visual recognition memory. She obtained a percentile score of 63 on the verbal recall test (People – raw score 29/36), a percentile score of 63 on the visual recall test (Shapes – raw score 35/36), and a percentile score of 84 on the verbal recognition test (Names – raw score 21/24). As expected, she was impaired in making familiarity judgments about individual doors in the Doors test, with a percentile score of 2 (raw score 13/24).

AW's accuracy score for delayed recall of the Rey–Osterrieth Complex Figure was determined by averaging the scores of two different raters (Rater 1: 25.5/36; Rater 2: 26.5/36). Her accuracy on the delayed recall portion of this test was 26 out of 36. Female, age-matched control subjects had a mean score of 20.4/36 using the same scoring system (SD = 4.77) (Gallagher and Burke, 2007), indicating AW's performance on this test was normal.

2.6. Basic-level object recognition and perception

Individuals with acquired object recognition deficits often are impaired in their ability to identify and discriminate objects at the basic level (e.g., identifying an object as a cup or chair: Feinberg et al., 1994; McMullen et al., 2000; Moscovitch et al., 1997). Given the parallels between her deficits and the deficits of patients with acquired object agnosia, we wanted to see if AW had difficulties with basic-level object processing.

2.6.1. Methods

To assess AW's ability to identify and make semantic judgments about objects, we administered the Picture Naming Test (short version) and the Object Decision Test from the Birmingham Object Recognition Battery (BORB: Riddoch and

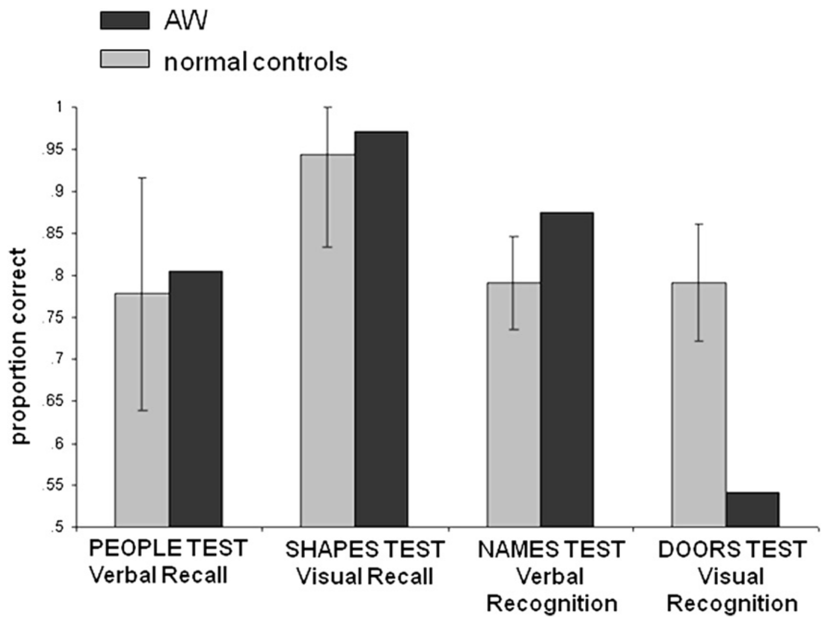

Fig. 2 – AW's results on the Doors and People test of visual and verbal memory (Baddeley et al., 1994) Columns show proportion correct for each subtest. Normal control scores are shown in grey, with bars indicating ±1 SD. AW's score is shown in black. Her performance was impaired on the Doors Test, which requires memory of door exemplars. Otherwise, AW's memory performance was normal.

Humphreys, 1993). To assess her ability to perceive and identify objects in three dimensions, we administered the BORB Foreshortened View and Minimal Feature View Tests. We tested AW's visual perception using three tests of visual closure taken from the Kit of Factor-Referenced Cognitive Tests: the Gestalt Completion Test, Concealed Words Test, and the Snowy Pictures test (Ekstrom et al., 1976). These tests require the identification of words and objects from images where part of the image has been erased or occluded.

2.6.2. *Results*

None of AW's scores on these tests differed significantly from the scores of normal control subjects, although it should be noted that the norms used in this comparison are based on those published by Riddoch and Humphreys (1993) using an older group of control subjects. AW's results on these basic-level object recognition and perception tests are shown in Table 2.

2.7. *Within-category visual perception*

AW's impairments with within-category object recognition could result from deficits in perception, memory, or abnormalities in both perception and memory. To distinguish between these possibilities, we investigated AW's ability to make within-category perceptual judgments using morphed stimuli.

2.7.1. *Methods*

We tested AW's within-category visual object perception using three tests with morphed object, face, and body images. These tests were used in a TMS experiment demonstrating category-specific performance disruptions based on different cortical stimulation sites (Pitcher et al., 2009). On each trial, an image was shown for 500 msec, followed by a 500 msec mask, 500 msec fixation, and then a second image for 500 msec. The second image was presented in one of two locations below and either to the right or left of the position of the first image. Participants were then asked to decide if the two images were the same or different. Each test contained 80 trials, with 40 same trials and 40 different trials. Image pairs on different trials varied in their degree of similarity to one another, yielding trials of varying difficulty. Faces in the face perception test were generated using FaceGen software (Singular Inversions; Toronto, ON, Canada). Novel objects in the object perception test were downloaded from Michael Tarr's website (http://titan.cog.brown.edu:8080/TarrLab/author/tarr). Body images were male bodies created using Poser software (Smith Micro, Inc.; Watsonville, CA). All bodies were headless, wore white shorts, and varied in muscle tone and corpulence.

For AW and all control participants, the morphed faces test was administered first, followed by the morphed objects test and the morphed bodies test. However, due to a computer error during administration, the data from AW's first attempt on the morphed objects test were lost. For this reason, we administered the morphed objects test a second time and report her score on this second attempt. To replicate the testing conditions with AW as closely as possible, we also administered two consecutive runs of the morphed object test to all controls and have used control scores from only the second run in our analysis.

2.7.2. *Results*

AW's scores from the morphed faces, objects, and bodies tests were compared with the performance of 10 normal control participants with a mean age of 26.7 years using *t*-tests

Table 2 – Results from other low-level, cognitive, and perceptual tests.

Low-level abilities			AW		Control mean (SD)
			# Correct		# Correct
Birmingham Object Recognition Battery[a]					
Test 2: length match			27		26.9 (1.6)
Test 3: size match			26		27.3 (2.4)
Test 4: orientation match			23		24.8 (2.6)
Test 5: gap match			36		35.1 (4)
National Adult Reading test (UK)[b]			29		38.8 (14.8)
Raven's Advanced Progressive Matrices Set I[c]			12		9 (1)
Wechsler Adult Intelligence Scale III: Digital Span[d]			# Digits recalled		# Digits recalled
Forward			5		6.6 (1.4)
Backward			5		4.9 (1.4)
Basic-level recognition and perception			AW		Control mean (SD)
Objects			# Correct		# Correct
Birmingham Object Recognition Battery[a]					
Test 13: Picture Naming			15/15		12.7 (2.2)
Test 10: Object Decision (A Hard Only)			26/32		27 (2.2)
Test 7: Minimal Feature View			25/25		23.3 (2)
Test 8: Foreshortened View			25/25		21.6 (2.6)
Kit of Factor-Referenced Cognitive test[e]					
Gestalt completion			19/20		15.2 (3.6)
Concealed words			36/50		23.6 (6.4)
Snowy pictures			15/24		5.7 (3)
Face and object detection					
Face and object array[f]	AW		Control mean (SD)		
	A′	RT (msec)	A′		RT (msec)
Faces	1.0	763	1.0 (0.003)		977 (170)
Bodies	1.0	1439	.9 (0.02)		1154 (284)
Birds	1.0	2719	.93 (0.04)		2595 (460)

None of AW's scores on these tests differed significantly from the scores of normal control subjects.
a Riddoch and Humphreys, 1993.
b Nelson, 1991.
c Raven et al., 1994.
d Wechsler, 1997.
e Ekstrom et al., 1976.
f Garrido et al., 2008a, 2008b.

adapted for analysis of single case studies (Crawford and Howell, 1998). Fig. 3 shows that her scores on the morphed face, object, and body perception tests were normal (faces: $t = .19$, $p = .43$; objects: $t = .48$, $p = .32$; bodies: $t = .24$, $p = .41$). Healthy control participants made more errors on trials where image pairs were more similar ($p < .001$ for all three tests based on repeated-measures ANOVA with morph percentage as within-subjects factor) and more errors overall on different trials than on same trials (paired samples t-tests; $p < .001$ for all three tests). AW showed the same pattern of results as control participants on all three tests. Her object perception score indicates that her impairments with object recognition tasks are due to deficits involving recognition memory processes rather than perceptual processes.

2.8. *Vision, I.Q. and other abilities*

AW scored normally on all other tests that we administered. Her scores were normal on tests of visual acuity and the Pelli–Robson test of contrast sensitivity (Pelli et al., 1988). AW's scores in other cognitive and perceptual tests are provided in Table 2.

3. Discussion

AW was impaired on a range of within-category object and scene recognition tests, but she performed normally on all tests of face recognition, including a test used to detect subtle face recognition deficits in individuals with DP. AW also demonstrated normal memory for other types of information, including visual recall of complex shapes, certain topographical stimuli (houses), and at least one visual object category (glasses). Extensive testing of AW failed to reveal any other cognitive or perceptual impairment and structural MRI gave no evidence of neurological abnormalities. AW's pattern of performance contrasts with the deficits of individuals with prosopagnosia, who are impaired on tests of face recognition, but can have normal object recognition memory (Duchaine and Nakayama, 2005; Duchaine et al., 2006; Nunn et al., 2001; Riddoch et al., 2008). AW's results provide the first evidence for the existence of a selective developmental deficit affecting non-face visual recognition memory. AW's normal face recognition alongside impairments in other areas of object recognition indicate that face recognition can develop

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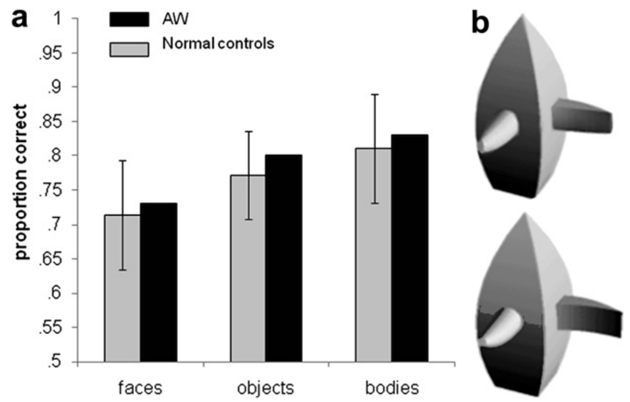

Fig. 3 – Within-category visual perception. (a) AW's scores are shown in black. Normal control scores are shown in grey, with bars indicating ±1 SD. Columns show proportion correct for each subtest. AW scored normally on all three tests of within-category visual perception, including object perception. (b) Sample images from the morphed objects test. Participants were to indicate if the two objects were the same or different. Images shown are from a "different" trial.

normally despite deficits in mechanisms necessary for other domains of within-category visual recognition.

There are several important differences between AW's pattern of impairment and the impairments of other visual agnosics. AW's deficit does not appear to affect her object perception abilities, suggesting that her case is best characterized as a form of associative agnosia (Lissauer, 1890). AW's pattern of impairment differs from patients with the classic form of acquired associative agnosia, however, as she has no difficulties identifying objects at the basic-level (Feinberg et al., 1994; McMullen et al., 2000; Moscovitch et al., 1997). AW's difficulties in within-category visual recognition make her similar to cases of developmental visual object agnosia, except that face processing was severely impaired in all previously reported cases (Behrmann et al., 2005; Duchaine and Nakayama, 2005; Gilaie-Dotan et al., 2009). AW also bears comparison to patients with hippocampal amnesia, where broad deficits in verbal, visual, topographical and episodic memory have been reported alongside intact memory for faces (Bird et al., 2007, 2008; Carlesimo et al., 2001; Cipolotti et al., 2006; Graham et al., 2006; Spiers et al., 2001). It is unclear how to interpret AW's pattern of impairment with respect to this literature, however, as her performance was normal to high on a range of other memory tests for which patients with hippocampal damage typically have significant difficulties. Based on our current data, we believe AW's difficulties are most likely the result of a limited, developmental impairment in her ability to encode and/or recognize certain types of visual information, useful for demanding forms of visual recognition such as recognition of within-category objects and scenes. The tests we administered do not exclude the possibility that AW has difficulty accessing semantic information for the items she has difficulty recognizing. However, based on her high level of everyday functioning, we think it is unlikely that AW's impairments extend to the semantic level. Future work with AW will address this possibility.

Why is AW impaired in her ability to recognize exemplars from some visual object categories, but not others? Given our poor understanding of the mechanisms underlying visual recognition and visual memory, the answer to this question is unclear. One possibility is that the recognition of eyeglasses, houses, and upright faces all rely on a common process that developed normally in AW. A number of findings have suggested that face processing is especially dependent on configural/holistic representation (Tanaka and Farah, 1993; Young et al., 1987; Yovel and Kanwisher, 2009), and it could be that eyeglass and house representations are as well. Another possibility is that these categories depend on a common memory process. However, psychophysical (Tanaka and Farah, 1993; Yin, 1969; Yovel and Kanwisher, 2009), neuroimaging (Epstein and Kanwisher, 1998), and neuropsychological (Bird et al., 2007; Carlesimo et al., 2001; Duchaine et al., 2006; Farah et al., 1995; Yovel and Duchaine, 2006) studies have shown dissociations between face processes and those processes mediating house and eyeglass recognition.

These dissociations suggest that AW's normal recognition of faces, eyeglasses, and houses may depend instead on multiple mechanisms that each developed normally. As discussed above, considerable evidence suggests that face processing depends on specialized mechanisms. We believe that AW's normal face processing simply reflects the operation of a face system that developed normally. Confident suggestions about the mechanisms underlying AW's normal house and eyeglass performance are much more difficult. Houses produce selective activation in the parahippocampus (Epstein and Kanwisher, 1998) and/or in the right lingual sulcus (Aguirre et al., 1998), but strong activations in these regions are also produced by scenes so it is unclear why AW showed such a clear impairment with natural scenes if these mechanisms are functioning normally. Eyeglasses are, of course, usually viewed while being worn on the face so there may be a close connection between eyeglasses and faces, but the dissociations mentioned above suggest that these two classes are processed separately. Based on previous evidence, we had expected eyeglass recognition to involve mechanisms similar to those used for other types of object recognition such as cars, tools, and guns. One final possibility worth acknowledging is that our tests may have permitted AW to achieve normal scores with houses and eyeglass via mechanisms different from those participants normally applied to these categories, in which case her house and eyeglass scores are best ignored.

Several selective developmental conditions have been identified that show a substantial level of heritability, indicating a genetic factor in their etiology (Pennington et al., 1991; Shalev et al., 2001; Tomblin, 1989). In AW's case, the opportunity to test her identical twin allowed us to examine whether AW's recognition deficit has a genetic basis. The normal performance of AW's twin in our tests suggests that the origin of her deficit is unlikely to be based on purely heritable factors. Given their shared family upbringing, it is also very unlikely that AW (and not her twin) was exposed to an exceptional, systematic environmental factor (e.g., impoverished early visual environment) that might explain her impairment. Instead, her poor within-category object recognition performance is more likely to be the result of some idiosyncratic neurodevelopmental abnormality or early subtle brain damage.

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In this paper, we have described a novel developmental deficit that adds to the growing list of selective developmental disorders that have been uncovered recently (Ayotte et al., 2002; Duchaine and Nakayama, 2006a; Garrido et al., 2008b; Iaria et al., 2008; Landerl et al., 2004; Ramus et al., 2003; van der Lely, 2005). Further research could elucidate whether AW's pattern of impairments represents a rare occurrence within the population, or a relatively common developmental abnormality as appears to be the case with DP (Kennerknecht et al., 2008). While it may seem improbable that object recognition deficits like AW's are as common DP, we would note that AW's deficits appear to have limited impact on her everyday functioning. It is unlikely that a tendency to lose things with otherwise intact psychosocial functioning (as appears to be the case with AW) would prompt an individual to seek medical counsel. Our results suggest that population screening is a useful means of identifying novel, theoretically interesting neuropsychological conditions with clinically subtle indications (Temple and Richardson, 2004, 2006).

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