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Dissociations of Visual Recognition in a Developmental Agnosic: Evidence for Separate Developmental Processes

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Abstract

We report the results of tests investigating the recognition of faces, places, and objects in a developmental agnosic, because dissociations of visual recognition in developmental agnosics provide insight into the separable procedures performing recognition and the developmental origins of these procedures. TA is a software engineer in his early 40s with developmental prosopagnosia. He performs normally on tests of low-level vision, and he names objects at the basic level normally. In order to compare his recognition abilities for different classes, we have presented him with a famous landmarks test, a famous faces test, and old/new discriminations involving unfamiliar faces, houses, natural landscapes, cars, horses, guns, sunglasses, and tools. He was impaired on the face recognition tests, but performed normally on the place recognition tests. He also showed severe impairments with horses and cars, borderline impairments with guns and sunglasses, and normal performance with tools. These results indicate that the developmental processes that assemble the procedures used for face recognition and certain types of object recognition are separate from those processes that produce the procedures used for place recognition.

Neuropsychological case reports of selective impairments of visual recognition have indicated that different classes of stimuli are recognized with different recognition procedures. The classes most commonly shown to dissociate are faces (Farah, 1996; Moscovitch *et al*., 1997; Nunn *et al*., 2001), animate objects (Farah *et al*., 1991; Hillis and Caramazza, 1991; Arguin *et al*., 1996), inanimate objects (Warrington and McCarthy, 1983, 1987; Hillis and Caramazza, 1991; Sacchett and Humphreys, 1992), and places (Hecaen, 1980; Incisa della Rocchetta, 1996). While the stimuli making up the first three classes are fairly straightforward, place or topographical recognition refers to the recognition of a location based on prominent environmental features (Aguirre and D'Esposito, 1999; Barrash *et al*., 2000; Epstein *et al*., 2001).

Based on the neuropsychological evidence, it appears that faces (McNeil and Warrington, 1993; Farah, 1996; Moscovitch *et al*., 1997; Henke *et al*., 1998; Humphreys and Rumiati, 1998; McMullen *et al*., 2000; Nunn *et al*., 2001) and places (Whiteley and Warrington, 1978; Hecaen, 1980; Incisa della Rochetta, 1996; Maguire and Cipolotti, 1998) are recognized by procedures not used for most other types of visual recognition. This evidence has been paralleled by lesion studies (Landis *et al*., 1986; DeRenzi *et al*., 1994; Barrash, 1998; Barrash *et al*., 2000; Epstein *et al*., 2001) and neuroimaging studies (Haxby *et al*., 1994; McCarthy *et al*., 1997; Aguirre *et al*., 1998; Epstein and Kanwisher, 1998; Tong *et al*., 1998; O'Craven and Kanwisher, 2001) implicating specific brain regions for each class. Although the evidence is sparser, neuropsychological cases (Warrington and McCarthy, 1983; Sartori and Job, 1988; Etcoff *et al*., 1991; Sacchett and Humphreys, 1992; Sartori *et al*., 1993a; Sartori *et al*., 1993b; Mehta and Newcombe, 1996) and neuroimaging studies (Perani *et al*., 1995; Martin *et al*., 1996) suggest that procedures carrying out animate recognition and inanimate recognition are also dissociable.

Although this evidence indicates the presence of independent procedures, the nature of the different procedures is controversial. Domain-specific computational accounts propose that these different classes are recognized by procedures specialized for these classes (Barrash *et al*., 2000; Kanwisher, 2000; Epstein *et al*., 2001). For example, such an account would explain selective dissociations of face recognition as damage to face-specific procedures. Domain-general accounts, in contrast, claim that visual recognition is carried

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out by mechanisms specialized for particular processes that can operate on a wide variety of classes (Kanwisher, 2000). In order to account for selective dissociations, domain-general accounts suggest that some processes are necessary for some classes but not for others (Warrington and McCarthy, 1987; Damasio *et al*., 1990; Farah, 1990; Tarr and Gauthier, 2000).

Selective dissociations in developmental agnosia

Despite the uncertainty regarding the nature of the dissociable procedures, the developmental origins of the procedures can still be approached. Dissociations between different classes in cases of developmental agnosia suggest that the dissociable classes are handled by procedures produced by different developmental processes. However, if certain classes of stimuli never dissociate in developmental agnosics, this suggests that these classes are recognized by procedures having a common developmental origin.

The most convincing developmental dissociations are those found in individuals who have had recognition impairments their entire lives. These impairments are usually the result of genetic deficits, prenatal or perinatal adverse events, or disease. Because it is possible that the seeds for dissociable procedures could be sown through exposure to different classes within the first weeks of life by a domain-general developmental process, our brief discussion below of developmental dissociations omits cases of agnosia brought about by events after birth. Although there are few well-documented reports that satisfy our criterion, those that do suggest that some recognition procedures are developmentally dissociable.

Cipolotti *et al*. (1999) reported on an individual, PE, with multiple developmental impairments who showed a clear impairment with unfamiliar face recognition and unfamiliar animal recognition. In contrast, his recognition of unfamiliar places was normal. Another developmental prosopagnosic, EP, has recently shown face recognition impairments coupled with normal place recognition and object recognition (Nunn *et al*., 2001). His object recognition was tested with naming tests involving flowers, cars, and famous buildings, and he performed normally on all three tests. Farah *et al*. (2000) tested a 16-year-old boy with severe face recognition impairments who had suffered brain damage at 1 day of age. He was able to name 26/30 photographs of everyday objects, but he had trouble naming line drawings, particularly line drawings of animate objects. However, he was not tested with object recognition tests involving specific individual items so it is not possible to directly compare his object and face recognition. Another developmental prosopagnosic, Dr. S., performed very badly on a familiarity discrimination test involving the faces of celebrities but performed normally in one involving objects (Temple, 1992). Bentin *et al*. (1999) reported a developmental prosopagnosic, YT, who was clearly impaired with face recognition, but had no trouble naming common everyday objects and it was mentioned that he was able to easily identify car models, familiar locations, and animals.

In addition, two studies have examined visual recognition memory in individuals with autism. Boucher and Lewis (1992) found that children with autism were impaired relative to learning-disabled children on an unfamiliar face recognition test, but not on a comparable house task. A group of adults with autism displayed impairments on recognition memory tests with faces, cats, horses, and motorbikes, but they showed no impairment with houses and leaves (Blair *et al*., 2002).

The clearest result from these reports is that some of the procedures performing face recognition and place recognition are developmentally dissociable. Less clear is the relationship of face and place recognition to object recognition. PE's impaired performance with faces and animate objects dissociated from his normal performance with places. In order to account for PE's results, Cipolotti *et al*. (1999) suggested that recognition procedures for faces and other animate objects are produced by one developmental process (Cipolotti *et al*., 1999), whereas other processes create dissociable procedures for places and inanimate objects. Based on work in cognitive development (Premack, 1990; Mandler and McDonough, 1993), they proposed that the infant visual system categorizes objects with cues to agency such as self-propelled motion as animate objects, and so predicted that vehicles would be recognized with procedures used for animate objects (Cipolotti *et al*., 1999; Blair *et al*., 2002). As a result, they predicted that faces, animals, and vehicles would developmentally fractionate from inanimate objects and places. This prediction is also supported by other cases (Boucher and Lewis, 1992; Blair *et al*., 2002; Farah *et al*., 2000), but is not consistent with some reports (Bentin *et al*., 1999; Nunn *et al*., 2001).

One weakness of these reports is that response times were not measured. Gauthier *et al*. (1999) have pointed out that lack of response times leaves the validity of dissociations in doubt, because speed/accuracy trade-offs are likely to impact performance. Without response time measures, one cannot rule out that agnosic subjects have produced normal accuracy scores with particular classes simply by taking more time to make their decisions with those classes. They buttressed their concerns by documenting two prosopagnosics who did show normal accuracy performance with object recognition tests, but examination of their slow response times indicated that they did, in fact, have object recognition difficulties. Because of this issue, the reports of normal performance discussed above are not unequivocal, so in the tests reported below, we will measure both accuracy and response time.

Next, we report the results of testing done with a developmental agnosic. Previous reports have demonstrated that a number of classes are developmentally dissociable, but the small number of cases makes it impossible to draw definite conclusions regarding the nature of the developmental processes that produce these dissociable procedures. Our investigation is aimed at determining whether TA's impaired face recognition dissociates from his place and object recognition.

If we find dissociations, these results will provide support for the computational independence of the procedures used to recognize the dissociated categories, and more importantly, any dissociations found will add to our very limited knowledge of the developmental dissociations possible in visual recognition.

Case history

TA is a 42-year-old, right-handed software specialist from Finland with a university degree in engineering who has suffered from face recognition difficulties his entire life. The first incident he recalls involving defective face recognition occurred at the age of eight when he mistakenly identified two strangers as his father and brother. Upon entrance into the army, he realized that something was seriously wrong. TA found the uniform appearances of the other servicemen difficult to cope with, and he likens his time in the army to a prison sentence. He reports incidents in which he has been unable to recognize all his close relatives (father, mother, wife, children, and brothers). Although he can recount many instance of failed recognition of familiar individuals, TA considers himself to be an ‘‘overrecognizer’’ in that he commonly falsely recognizes strangers.

TA also reports that he has difficulty recognizing facial expressions of emotion, and preliminary testing indicated he does, in fact, have problems with emotions. He does not report any object recognition difficulties, but tests discussed below demonstrate that he does have impairments for at least certain types of object recognition. TA shares his prosopagnosia with his son (his son’s prosopagnosia has been clinically confirmed with the Benton Facial Recognition test (Benton *et al.*, 1983)), and he also reports that his mother and possibly his maternal grandmother have impairments with face recognition. Given his family history, it is clear that the origin of TA’s agnosia is genetic. Neither TA nor his son has any trouble recognizing places or navigating, but he believes that both his mother and his grandmother have navigational impairments. Neither of TA’s daughters appear to be prosopagnosic.

TA fulfills the ICD-10 (1993) and the DSM-IV criteria for Asperger syndrome (1994). The essential criteria imply normal language and cognitive development, qualitative impairment in reciprocal social interaction, and restricted, repetitive, and stereotyped patterns of behavior, interests, and activities (Gillberg and Gillberg, 1989). TA was diagnosed by means of a detailed, structured interview involving a close relative according to principles outlined by Gillberg and Gillberg (1989), Ehlers and Gillberg (1993), and Ehlers *et al.* (1999) using the ASDI (Asperger Syndrome Diagnostic Interview). During the diagnostic interview as well as during the testing, he was not taking any medication. TA has not had any history of psychiatric disorders. TA’s mother has also been diagnosed with Asperger syndrome.

His occupation and his scores on intelligence tests demonstrate that TA is an extremely bright individual. His WAIS-R Verbal IQ was 127, and his Performance IQ was 144. He is a fast and voracious reader (which indicates no trouble with word recognition), and his keenest interests are in astronomy, photography, trains, and railroads.

The testing reported herein was carried out in two sessions. One of the authors (BD) tested TA in September 2000 when TA was attending a workshop at Stanford University, and another author (TN-vW) did follow-up testing at the University of Helsinki in March, 2001 and September, 2002. In both sessions, he was alert and fully co-operative, and his speech was fluent and precise. His English is quite good, so all of the instructions were presented in English and TA’s verbal responses with BD were in English.

Neuroradiological examination

TA underwent a 1.5T brain MRI using T1-weighted sagittal slices (slice thickness 1 mm) covering the entire brain. The central CSF spaces were normal for his age. His right lateral ventricle was slightly larger than his left lateral ventricle, but the variation was within the normal range. The grey/white matter differentiation was normal, and the cerebrum was normal. The only noticeable abnormalities were sulci that were clearly larger than normal in the parietal lobes and in the upper part of the occipital lobes.

Tests of low-level vision

The central visual acuity of both of TA’s eyes was 1.0 when TA was tested with his eyeglasses. Fundoscopy showed that the central areas of TA’s retinae were normal and his visual fields were normal.

We also tested TA’s low-level vision with tests from the Birmingham Object Recognition Battery (BORB) (Riddoch and Humphreys, 1993). The control results are from the BORB manual. TA had no difficulty copying the figures and objects presented in the Copying test. His perception of elementary features was tested with four matching tests that require the subject to discriminate whether a particular aspect of two figures is the same or different. TA’s scores were 28/30 on the Length Match, 29/30 on the Size Match, 28/30 on the Orientation Match, and 37/40 on the Gap Match, and each of these scores was slightly better than the control mean. On the overlapping figures test, the time it takes subjects to identify overlapping shapes, letters, or common objects is compared to the time required to name these same stimuli when they are not overlapping, and TA easily identified the overlapping stimuli.

Tests of basic level object recognition

Face recognition involves identification of a particular face, whereas object recognition often involves identification of an object’s basic level class such as television, football, or book. In order to assess TA’s basic level object recognition, we presented him with digitized versions of 100 line drawings from Snodgrass and Vanderwart’s set (1980). Based on a prior classification of this set (Farah *et al*., 1991), the set of 100 consisted of 65 living and 35 non-living objects. TA was able to name the objects immediately and nearly flawlessly (despite answering in English), so it does not appear that he has a recognition impairment for basic level objects.

Face decision tests are commonly used to determine if prosopagnosics can discriminate between normal facial configurations and faces with misplaced features. In our test, subjects are presented with a stimulus for 100 milliseconds on a computer monitor and after the image is removed they are asked to decide whether or not the stimulus is a face. The stimuli were created by pasting features from hand-drawn faces into the outline of a head. The scrambled faces had the misplaced features in locations normally occupied by the proper features. The features in both the faces and the non-faces were pasted in so that subjects could not discriminate based on the presence of pasted features. TA's score of 59/60 was better than the undergraduate and graduate student control mean of 55.7 and his response times were also normal, so he does not appear to have any trouble discriminating faces from scrambled faces.

Face recognition

Different views test

Subjects were presented with a frontal view of a face for 3 s and then required to decide which one of three three-quarter profile photos showed the individual in the frontal shot. The three-quarters profile photos appeared immediately after the frontal shot was removed from the screen. Adult men's faces were used for 15 of the trials, and adult women's faces were used for the other 15. Sixteen undergraduate control subjects averaged 27.1/30 (SD = 1.3); TA's score of 17/30 was far out of the normal range.

Face one in ten test

In this test, participants were asked to recognize 15 photos of a target individual, which differ in angle of illumination, out of 150 photos presented one at a time. The faces in these black and white photographs were cropped so that only the internal facial features were visible. In the study phase, three photos of the target individual were cycled through three times for 3 s per photograph. Following this, participants were presented with test faces, one at a time, and they were asked to respond as quickly as possible with a mouse click whether or not the photo displayed the target individual. There was an average of five photographs of the target individual in each set of 50. None of the study faces were used as test faces, and the 135 distracter faces consisted of 15 different images of nine individuals. The 150 test photographs were broken into three groups of 50, and the target faces were presented prior to each set. There were three target faces so there were 450 trials (3 targets × 150 images). The first set was a practice set so 400 trials were included in the analysis.

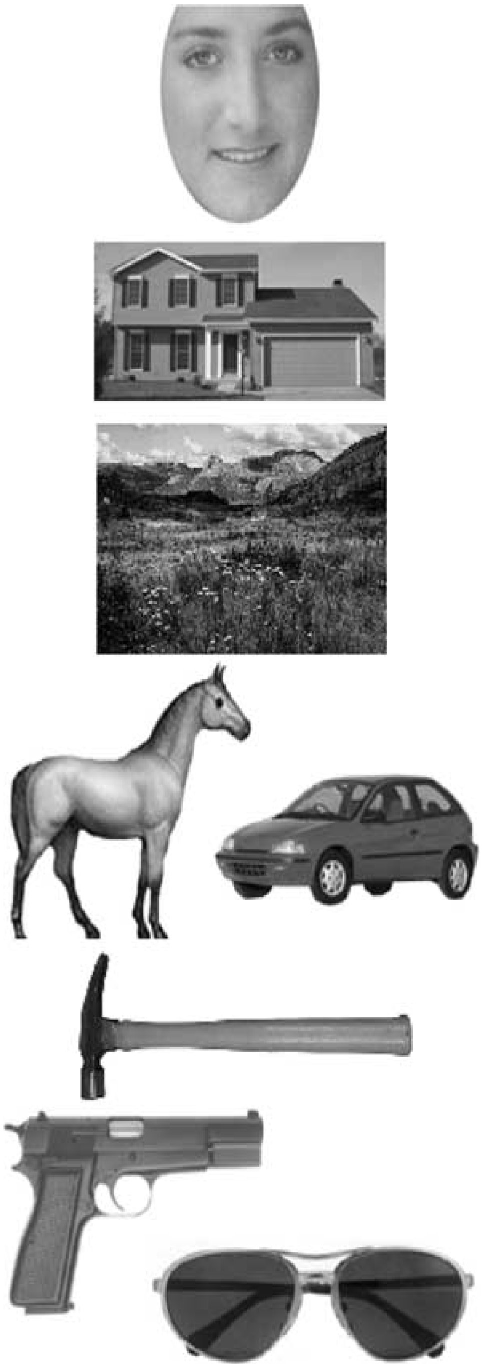

Fig. 1. Items from the old/new discriminations.

A signal detection analysis was used to determine TA's ability to discriminate between target and distracter individuals. Compared to 13 control subjects, TA was significantly less able to discriminate between targets, and he was much slower. The mean d′, the measure of discrimination, was 3.61 (s.d. 0.486) for undergraduate and graduate controls; TA's score of 1.01 is more than five standard deviations below the mean. In addition, his response times were significantly slower than the controls. Control subjects' 'yes' responses averaged 774 ms (SD = 121) and their 'no' responses averaged

530 ms (SD = 87); TA's 'yes' responses averaged 1254 ms (z = 3.97) and his 'no' responses averaged 1046 ms (z = 5.93). TA's normal performance on other timed tasks demonstrates that his slow response times were not due to slow motoric responses, but were due to his face recognition difficulties.

Face old/new discrimination tests

We tested TA with two tests that used identical methods, but used different sets of faces. Participants were presented with the ten target faces for this task for 3 s per face, and the ten faces were cycled through twice. The black and white photographs of the target individuals were identical throughout the task, and all of the faces used in this task were frontal views of young women (see Fig. 1). During the test phase, participants were presented with faces one at a time and were asked to respond whether a face was a target face or a non-target face as quickly as possible with a mouse click. A total of 50 test faces were presented consisting of 20 target faces (10 targets × 2 presentations) and 30 non-targets (30 non-targets × 1 presentation).

The same group of graduate student controls was used for all of the old/new discriminations in this report. This group consisted of 17 individuals (8 men and 9 women) who were paid for their participation. On some of the tests, we were unable to obtain useable results from control participant due to computer problems, but we never lost the results from more than one participant so all samples include either 16 or 17 participants. Men and women performed very similarly except on the discrimination test with sunglasses. Unequal n t-tests were used for all of the statistical comparisons with the old/new discriminations. For each discrimination test, the comparison between TA's response times and the controls' mean response times are discussed, and Table 1 presents these response times and the significance level of the statistical test.

Faces 1

The d′ of the 16 graduate student control participants was 3.09 (SD = .50). TA's d′ was 1.10 was significantly lower than the controls (t(15) = 3.83, p = .0008) (see Fig. 2). TA's response time for hits was marginally slower than the control mean while his correct rejections response mean was not significantly slower (see Table 1).

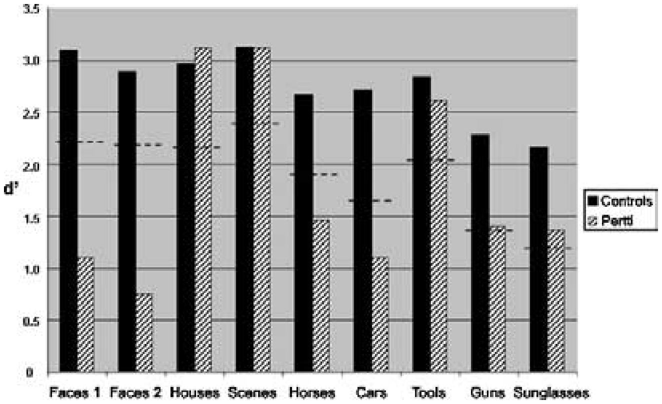

Fig. 2. TA's discrimination performance (d′) compared to the control participants on the old/new discrimination tests. Scores below the dashed lines are significantly out of the normal range.

Faces 2

The 16 controls' d′ was 2.89 (SD = .40), and TA's d′ of .75 placed him far out of the normal range (t(15) = 5.18, p = .0001). TA's response times were much longer than the controls' response times.

Famous face recognition

Participants in this test were presented for 10 s with the face of a well-known celebrity in a photograph cropped so that little hair or clothing was visible. They were asked to name the individual or provide other information that uniquely identifies that individual such as a political office or an acting role. There were a total of 25 famous faces, and 16 undergraduate controls were able to name 23.6/25 (SD = 1.41). In stark contrast, TA was able to name only 3/25, and he incorrectly guessed a number of times.

Because TA is Finnish, it is especially important to establish that he had exposure to these celebrities. He was presented with a paper-and-pencil matching task that asked him to match the names of the celebrities with their profession or some other distinguishing characteristic. TA was asked not to

Table 1. Response times for the old/new discrimination tests

	Hits				Correct Rejections			
	Controls				Controls			
	Hit Mean	Hit SD	TA	p value	CR Mean	CR SD	TA	p value
Faces 1	935	226	1301	*0.07*	928	221	1173	ns
Faces 2	944	216	2999	*0.0001*	950	184	2292	*0.0001*
Houses	965	230	881	ns	967	182	872	ns
Scenes	905	206	967	ns	852	204	926	ns
Horses	1151	366	963	ns	1149	252	1083	ns
Cars	1203	451	1022	ns	1157	415	1071	ns
Tools	958	294	835	ns	947	264	1083	ns
Guns	1093	278	985	ns	1191	304	1209	ns
Sunglasses	886	175	1200	*0.05*	959	152	918	ns

guess. He scored 21/25 on this task, and reported many occasions in which he had seen these individuals. Thus, his famous face score corrected for exposure was 3/21.

Place recognition

In order to assess his place recognition and compare it to his face recognition, we presented him with two types of place recognition tests. Our famous place recognition test is comparable to the famous face recognition test discussed above. We also presented TA with two old/new discrimination tests, one with houses and one with natural landscapes.

Famous place recognition

Participants were presented with 26 color photographs of well-known landmarks. These landmarks consisted of buildings (Notre Dame, Space Needle, Leaning Tower of Pisa), monuments (Great Sphinx, Arc de Triomphe, Washington Monument), and assorted other landmarks (Golden Gate Bridge, Great Wall of China). The stimuli were presented for 10 s, and the participants were instructed to identify the landmark with its name or other identifying information.

Forty undergraduate control participants were able to correctly name 18.2/26 (SD = 4.47) of the famous places. TA's score of 20/26 places him slightly above the control mean.

Old/new discriminations

These tests used the same paradigm and controls participants described above for the face old/new discrimination tests. Ten target stimuli were presented during the study phase, and subjects were required to discriminate between target and non-target stimuli in the test phase.

Houses

The color photographs used in the house test contained typical looking houses photographed from the front with some of the yard surrounding the house visible. The d′ of 17 graduate student control participants was 2.97 (SD = .46), and TA's d′ of 3.12 places him slightly above the control mean (see Fig. 1). Speed/accuracy trade-offs cannot explain TA's normal discrimination, because his response times were faster than the controls' response times (see Table 1).

Natural scenes

Black and white photographs of natural landscapes were used that did not have any man-made structures, and eight landscapes were used from each of the following five categories: beaches, lakes, meadows, mountains, and deserts. Two images were chosen from each category to serve as targets. The d′ for the 17 control participants was 3.10 (SD = .41). TA's d′ of 3.12 was very close to the normal control mean. His response times were also normal.

Object recognition

TA has severely impaired face recognition with normal place recognition. In order to assess TA's object recognition, we have presented him with five old/new discrimination tests involving horses, cars, tools, guns, and sunglasses. The paradigm in these tests is identical to that used with faces, houses, and natural scenes.

Horses

The stimuli for this test consisted of color photographs of model horses made by Breyer Animal Creations placed on a white background. The photographs presented a side view of the horses, and their poses were similar. The average d′ of the 16 controls was 2.67 (SD = .43), and TA's d′ of 1.46 was significantly less than the control mean ($t(15) = 2.70$, $p = .008$). Although TA's horse discrimination was impaired, his response times were in the normal range.

Cars

The cars used in these black and white images had all conspicuous ornaments removed, and were placed on a white background facing the same direction. Each car was categorized by style (compact, sedan, etc.), and they were divided proportionally into targets and non-targets. TA's d′ of 1.10 was significantly less than the d′ of 2.71 (SD = .61) for the 17 controls ($t(16) = 2.55$, $p = .011$). His response times were in the normal range.

Tools

This test used black-and-white photographs of eight examples from each of the five types of common tools presented (saws, hammers, pliers, wrenches, and screwdrivers). Two items from each category were chosen as targets, and all items from particular categories were presented in a similar orientation. Unlike the other object recognition tests, TA's performance with tools showed no signs of impairment. The d′ of the 17 graduate student controls was 2.83 (SD = .46), and TA's d′ was 2.61. TA's response times were in the normal range.

Guns

Color images of handguns were placed on a white background pointing in the same direction. They were placed into different categories and divided proportionally between targets and non-targets. The d′ for the 16 controls was 2.28 (SD = .53) whereas TA's d′ was 1.40. This score is borderline impaired ($t(15) = 1.62$, $p = .064$). His response times were in the normal range.

Sunglasses

Color images of sunglasses with their sidepieces folded behind them were presented on a white background. Again, TA's d′ was borderline impaired. Controls' d′ was 2.15 (SD = .55), and TA's d′ was 1.37 ($t(15) = 1.38$, $p = .094$). His accuracy performance is significantly impaired when percent correct is analyzed rather than d′. Controls averaged 85.5% (SD = 7.6) whereas TA percent correct was 68.0% ($t(15) = 1.38$, $p = .094$). His response time average for hits was significantly slower than the controls' average. In contrast, TA's average response time for misses was slightly faster than the control mean. We realized after TA and the control participants had completed this test that a programming error had caused one of the target sunglasses to be shown only once, not twice. We omitted the two test trials with this target item in a reanalysis of the results for TA and the controls, but the recalculated significance tests were nearly identical.

It should be noted, however, that the sunglasses test was the only test in which the performance of the men and women control participants differed appreciably. Although this difference did not reach significance for d′ ($t(14) = 1.80$, $p = .094$) or percent correct ($t(14) = 1.75$, $p = .102$), the mean for the men was notably lower than the mean for the women. TA's accuracy was worse than any of the men, but it was not significantly different than the mean for the men.

Discussion

TA's scores were normal for the famous places test and the discriminations with houses, natural scenes, and tools. In contrast, he showed severe impairments with the famous faces test and the discriminations with faces, cars, and horses, and he showed borderline impairments with guns and sunglasses.

Face recognition and topographical recognition

TA's severely impaired face recognition and normal place recognition reinforce past research indicating that the procedures for face and place recognition are produced by different developmental processes (Cipolotti *et al.*, 1999; Nunn *et al.*, 2001; Blair *et al.*, 2002). Unlike previous dissociations, speed/accuracy trade-offs cannot account for the dissociation, because measures of both discrimination and response time were made in the old/new discriminations. However, as Cipolotti *et al.* (1999) pointed out, the cases supporting the developmental dissociation of face and place recognition have all shown impaired face recognition with normal place recognition. As a result, there is not yet evidence for a developmental double dissociation between face and place recognition.

TA's results (see Table 2) are similar to the results for PE (Cipolotti *et al.*, 1999), but TA's dissociation between face recognition and topographic recognition is more complete. Whereas PE was able to recognize famous faces, TA was extremely impaired with famous faces yet recognized famous places normally. His results indicate that face recognition and place recognition rely on separate mechanisms for both short-term recognition and long-term recognition.

One interesting aspect of TA's case is that he reports that his mother and maternal grandmother were impaired with both faces and places whereas he and his prosopagnosic son can recognize places normally. Although there are a number of potential explanations for this pattern, it suggests that the genetic basis of their agnosia may manifest itself differently in different individuals.

Dissociation between object recognition and topographical recognition

TA's normal place recognition contrasts with his impaired recognition of horses and cars and his difficulties with guns and sunglasses. This is consistent with other individuals that have shown normal place recognition with impaired object recognition (Bentin, 1999; Cipolotti *et al.*, 1999; Nunn *et al.*, 2001; Blair *et al.*, 2002), and TA's results are especially convincing because he had normal response times in the place discriminations. Past dissociations between places and objects have only involved animate objects, not inanimate objects. However, TA's difficulties with guns and sunglasses suggest that place recognition can dissociate from inanimate recognition, and this conclusion is bolstered if cars are categorized as inanimate objects rather than animate objects. While his difficulties with guns and sunglasses were not profound, his scores were quite poor relative to his place scores so this is the best evidence that the procedures used to recognize inanimate objects develop differently from those used for place recognition. There are other potential demonstrations, but it is unclear whether the visual system categorizes leaves and motorbikes as inanimate objects (Blair *et al.*, 2002).

Given his difficulties with guns and sunglasses, TA's normal performance with tools is noteworthy. It is possible that TA was able to perform normally by using an alternative strategy such as noting small details of the tools rather than their overall form. However, the number of tools in the test, and the similarity of the targets and the non-targets would make this difficult and would presumably slow response times. In addition, it is not apparent why the tools test would be more susceptible to such a strategy than other tests on which he performed poorly. In future studies we will examine whether TA shows further dissociations between different inanimate categories. If he does, it will suggest that visual recognition procedures do not treat inanimate objects as a category or that inanimate recognition dissociates into finer categories.

It is worth noting that, despite their dissociability, place recognition and object recognition are likely to be intimately related. Recognition of places will often depend upon recognition of objects in a configuration. It seems likely that basic level recognition of objects will often suffice for place recognition so it is not surprising that individuals with object agnosia for individual items within a class can perform normally with place recognition. Likewise, place information has been shown to facilitate the recognition of context appropriate objects (Biederman *et al.*, 1973; Palmer, 1975).

Face recognition and non-face recognition can dissociate

In the introduction, we mentioned that Gauthier *et al.* (1999) have pointed out that in order to decisively demonstrate a dissociation between different classes, it is necessary to measure both accuracy and response time. This led them to question past reports of apparent dissociations of face and non-face recognition, because past reports did not measure response time. TA's impaired performance with faces coupled with normal discrimination and normal response times with houses, natural landscapes, and tools demonstrates that face and non-face recognition can dissociate.

In addition, TA's response times indicate that speed/accuracy trade-offs may not be a likely explanation for all of the questioned dissociations from past cases. Gauthier *et al.* (1999) suggested that prosopagnosics are likely to show short latencies with tests involving faces, because they are aware that they have trouble recognizing faces and so would not struggle to correctly answer these items from face tests. In contrast, it was suggested that they may struggle with test items involving non-face classes, because they believe that they can recognize non-face classes normally. TA's pattern of response times, however, contradicted this suggestion. On the Face One in Ten test and the face old/new discriminations, his response times were slower than the controls. In contrast, his response times for hits and correct rejections on the other seven object discriminations were near the control mean (except for correct rejections with sunglasses). His pattern indicates that short latencies with faces and long latencies with non-faces may not be a typical pattern for prosopagnosics, and many other prosopagnosics have shown abnormally slow response times with faces (Newcombe, 1979; Duchaine, 2000; Nunn *et al.*, 2001). As a result, it seems unlikely that all of the past reports of dissociations between impaired face recognition and normal non-face recognition were produced by speed/accuracy trade-offs. Some of these cases probably represent true dissociations between face and non-face recognition.

Table 2. Summary of TA's results

Test	Results
Visual acuity	Normal
Fundoscopy	Normal
BORB	
Copying	Normal
Length match	Normal
Size match	Normal
Orientation match	Normal
Position of gap match	Normal
Overlapping figures	Normal
Snodgrass line drawings	Normal
Face decision	Normal
Face recognition	
Famous faces	Impaired
Different views	Impaired
Face one in ten	Impaired
Faces 1 old/new	Impaired
Faces 2 old/new	Impaired
Place recognition	
Famous places	Normal
Houses old/new	Normal
Natural landscapes old/new	Normal
Object recognition	
Horses old/new	Impaired
Cars old/new	Impaired
Tools old/new	Normal
Guns old/new	Borderline
Sunglasses old/new	Borderline

Summary

TA showed impairments with face, horse, and car recognition, and borderline impairments with guns and sunglasses. This contrasts with his normal place and tool recognition. His dissociations and other reports of selective impairments in developmental agnosics indicate that separate developmental processes assemble different recognition procedures. Although it is clear that a common developmental process cannot account for these results, the paucity of reports makes it impossible to determine how to characterize the different developmental processes. Given the number of dissociable classes, there are many developmental scenarios, and so it will require the assessment of many developmental agnosics on a broad number of classes to sort out these possibilities.

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Dissociations of visual recognition in a developmental agnosic: Evidence for separate developmental processes

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Abstract

We report the results of tests investigating the recognition of faces, places, and objects in a developmental agnosic, because dissociations of visual recognition in developmental agnosics provide insight into the separable procedures performing recognition and the developmental origins of these procedures. TA is a software engineer in his early 40s with developmental prosopagnosia. He performs normally on tests of low-level vision, and he names objects at the basic level normally. In order to compare his recognition abilities for different classes, we have presented him with a famous landmarks test, a famous faces test, and old/new discriminations involving unfamiliar faces, houses, natural landscapes, cars, horses, guns, sunglasses, and tools. He was impaired on the face recognition tests, but performed normally on the place recognition tests. He also showed severe impairments with horses and cars, borderline impairments with guns and sunglasses, and normal performance with tools. These results indicate that the developmental processes that assemble the procedures used for face recognition and certain types of object recognition are separate from those processes that produce the procedures used for place recognition.

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