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Research report

A selective deficit in the appreciation and recognition of brightness: Brightness agnosia?

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ABSTRACT

We report a patient with extensive brain damage in the right hemisphere who demonstrated a severe impairment in the appreciation of brightness. Acuity, contrast sensitivity as well as luminance discrimination were normal, suggesting her brightness impairment is not a mere consequence of low-level sensory impairments. The patient was not able to indicate the darker or the lighter of two grey squares, even though she was able to see that they differed. In addition, she could not indicate whether the lights in a room were switched on or off, nor was she able to differentiate between normal greyscale images and inverted greyscale images. As the patient recognised objects, colours, and shapes correctly, the impairment is specific for brightness. As low-level, sensory processing is normal, this specific deficit in the recognition and appreciation of brightness appears to be of a higher, cognitive level, the level of semantic knowledge. This appears to be the first report of 'brightness agnosia'.

1. Introduction

The concept of a higher-order modality-specific recognition deficit was first suggested by Lissauer (1890), and it was Freud (1891) who subsequently coined the term (object-) agnosia. Further studies suggested even more selective deficits, such as agnosia for faces or prosopagnosia (Bodamer, 1947) and colour agnosia (e.g., Klein and Stack, 1953). Agnosia (a-gnosis, ''non-knowledge'', or loss of knowledge) is generally defined as the loss of ability to recognise for example objects, faces, shapes or colours, despite intact visual perception and memory (Bauer and Demery, 2003). These impairments do not have their origins in impairments of detection or discrimination of primary visual cues, such as luminance contrast, colour, acuity, and orientation, but are considered impairments of (detailed) visual knowledge. Beyond the very earliest stages for visual processing, different visual primitives (e.g., shape, luminance, colour, and motion) appear to be processed in distinct areas of the brain, and damage to these areas of the brain can lead to different kinds of visual deficits. Of the different visual primitives, shape agnosia (Campion and Latto, 1985; Milner et al., 1991) and colour agnosia (Davidoff, 1991, 1996; Steeves et al., 2004; van Zandvoort et al., 2007) have been especially well studied and well described.

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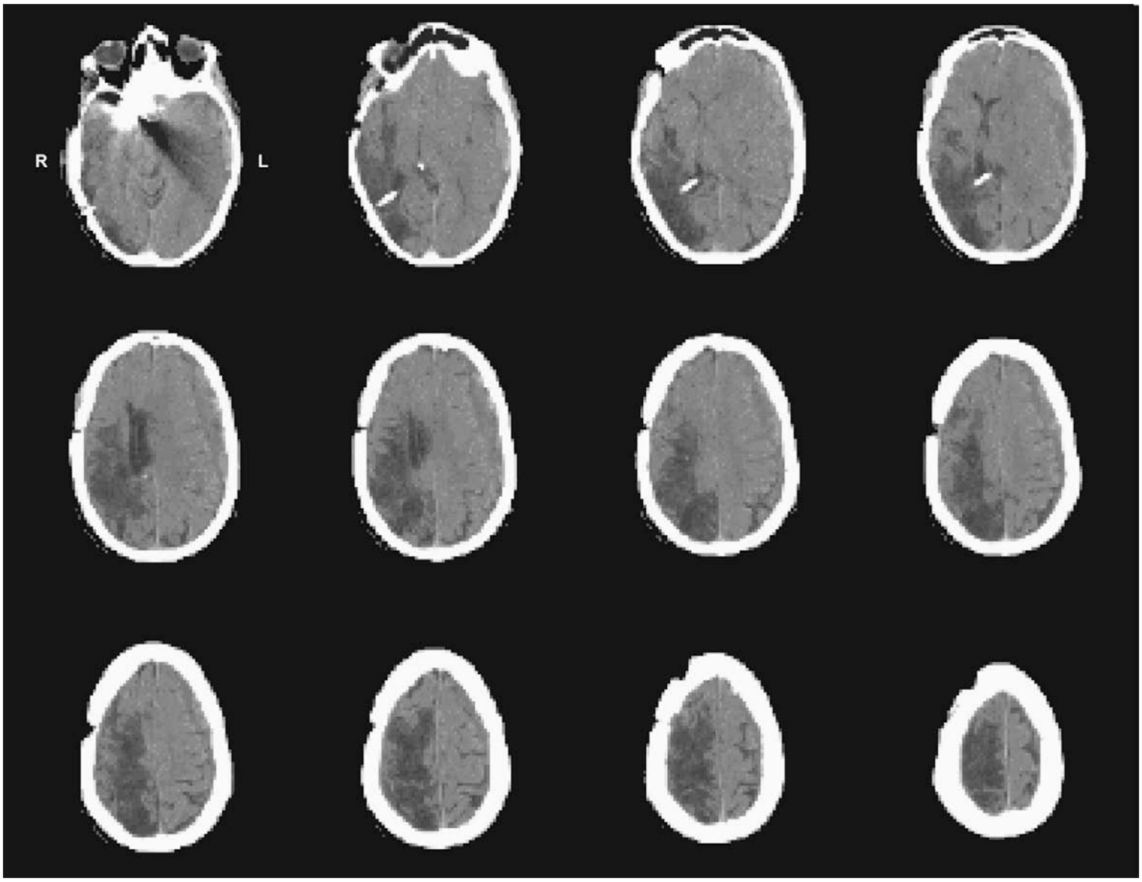

Fig. 1 – CT scan (2005) showing clip artifacts in the right frontal region, a ventricular peritoneal drain from the right lateral ventricle, a large cortical infarct in the right hemisphere, and a SDH in the left hemisphere.

The patient we report here has a selective impairment in recognising brightness[1] and darkness, in absence of low-level sensory-perceptual deficits. To the best of our knowledge, no case of "brightness agnosia" has been reported in literature so far. The aim of the present study was to describe this patient and to examine several aspects of bright- and darkness recognition and discrimination in more detail. Throughout the paper, we have used the comparison to colour agnosia in a descriptive manner.

2. Case report

LZ is a 66-year-old right-handed female, who suffered a subarachnoid haemorrhage (SAH) in September 2000. The ruptured aneurysm was successfully clipped, but one day after surgery, she developed severe vasospasms, which resulted in a large infarct of the right hemisphere involving the parietal, temporal, and occipital lobes with extensions into the frontal region. Retrospection of early neuropsychological reports suggested severe left-sided neglect and left-sided hemiparesis. In 2005, her husband noticed that she had language problems and she was admitted to a hospital where a subdural haematoma (SDH) was detected over the left hemisphere. The language disorder disappeared following evacuation of the SDH via a burr hole (see Fig. 1).

By the time she was examined in our laboratory for the first time (July 2006; after the left hemisphere SDH), she showed normal language and memory functioning [Boston Naming Test 34th percentile (average performance); Rey Auditory Verbal Learning Test (RAVLT) immediate recall: 10th decile (above average performance); RAVLT delayed recall: 7th decile (average performance); RAVLT recognition: 10th decile (above average performance)], and moderate left-sided visual neglect (BIT Line Bisection: 3/9; Star Cancellation: 47/54; Letter Cancellation: 35/40; Line Cancellation: 30/36; Representation Drawing: 2/3; Figure and Shape Copying: 1/4).

LZ's husband told us that she had additional problems appreciating whether lights were switched on or off since the SAH in 2000. The first time he became aware of this was when she was admitted to a rehabilitation centre in 2001. He noticed that when he left her in the evening and switched off the light for her to go to sleep, she switched it back on again. When he quizzed her about this, she claimed to have switched the light off to go to sleep. As a more recent example, he told us that, one night, he had asked her what time it was, as she has an alarm clock next to her bed. Even though the lights were still on, she replied that she could not tell him the time as it was dark and

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[1] In this paper, we use the term *brightness* for 'perceived luminance' and the term *lightness* for 'perceived reflectance' (Jando et al., 2003).

the arms of the clock are not luminous. A third example indicates that she uses strategies to find out whether the lights are switched on or off. In their bathroom, she used to see whether the lights were on by the position of the light switch. After they had their bathroom refurbished, she could no longer use this strategy, as there are now two switches. She now has to ask her husband whether the light in the bathroom is on or off.

We set out to investigate her basic visual-sensory functions (luminance, colour, shape), and subsequently her higher-order visual skills, specifically her ability to appreciate or recognise brightness.

3. Experiment 1: clinical assessment of sensory processing

3.1. *Method and procedure*

Two routine clinical tests for the assessment of sensory processing were used. First, we administered the Freiburg Acuity and Contrast Test (FrACT; Bach, 1996, 2007) for assessing visual acuity (VA) and contrast sensitivity (CS). Both were conducted on a 17-inch monitor (60 Hz). The luminance of the monitor was linearised by the built in psychophysical calibration routine of the FrACT. The FrACT VA test adjusts the size of the target, a Landolt ring (C), across trials. With correct responses, the target and thus the width of the gap, becomes smaller, whereas an incorrect response would expand the target in the next trial. Viewing distance was 2.5 m. VA thresholds were recorded in decimal form at the end of the test run, which comprised 60 trials. Decimal acuity scores were converted to Snellen fractions scores for data analysis. The FrACT CS test estimates the contrast threshold in a similar vein; the diameter of the target is constant, whereas the contrast is adjusted across trials by modulating the luminance level of the Landolt ring (C) on an intermediate grey background. With correct responses, the luminance level of the target decreases, whereas an incorrect response would increase the target's luminance level in the next trial. Viewing distance was 2.5 m. At the end of the 60-trial test run, the participant's Michelson contrast ratio was calculated $[(L_{\max} - L_{\min})/(L_{\max} + L_{\min})]$, corresponding to the difference between the target and the background luminances divided by their sum. Both tests use Best parameter estimation by sequential testing (PEST) adaptive threshold estimation to adjust the difficulty up, or down and participants used the arrow keys on the keyboard to indicate the orientation of the gap.

The second clinical test of early luminance processing was the Munsell Neutral Value Scale (Munsell Color Services, New Windsor, UK). This scale is a standard scale of neutral greys that measures lightness (i.e., reflectance) discrimination. The neutral greys range from absolute black (0% reflectance) to absolute white (100% reflectance) in 31 steps that look equal to the eye under standard viewing conditions. All greys were randomly placed in front of LZ and only the absolute black and the absolute white were placed on both ends of a sorting line. LZ was asked to sort all remaining 29 greys into a neat sequence between the given absolute black and absolute white. For each correctly placed grey, 1 point was given, with a maximum of 29. Additionally, we used a passive sorting task in which LZ had to indicate which of two arrays of achromatic squares was sorted with respect to luminance (from dark to light or vice versa).

3.2. *Results and discussion*

The data of LZ were compared to a group of 6 age-matched controls (mean age: 64, standard deviation – SD: 4.8; all had normal or corrected to normal vision).

To compare the VA and CS thresholds and the performance on the Munsell Neutral Value Scale of LZ to the mean thresholds and performance on the Munsell Neutral Value Scale of the control group, we used Crawford and Garthwaite's (2002) significance test on differences between an individual's score and the control sample. As can be seen in Table 1, all thresholds of LZ fell within the normal range of the control participants. LZ made 1 error switching 2 greys in the medium grey category. It should be noted that the amount of time LZ needed to finish this test, however, was about 4 times the time the control participants needed to finish this test (about 12 min). In the passive sorting task, LZ was significantly worse compared to controls ($t(5) = -8.265, p < .001$). This indicates that although LZ's VA and CS are within normal range, she has problems with recognising sorted greyscales and is extremely slow in actively sorting greyscales. This slowness in the active categorisation task is probably the result of comparing each grey to the others to finally make one sorted line.

4. Experiment 2: visual-sensory assessment

4.1. *Method and procedure*

Assessment of the perception of primary visual-sensory cues (shape, luminance, colour, and motion) was carried out with an odd-one-out procedure (De Haan et al., 1995). The different visual-sensory cues were individually tested in four separate tests, in which three stimuli were centrally presented in

Table 1 – Overview of the VA and CS scores of LZ and the healthy controls

	LZ	Healthy controls	Significance (one-tailed probability)
VA decimal	2.24	2.72 (SD: 1.75)	$T(5) = -.260, p = .400$
VA Snellen	6/2.7	6/2.62 (SD: .851)	$T(5) = .090, p = .465$
CS	.129	.149 (SD: .59)	$T(5) = -.307, p = .383$
Active sorting: (Munsell Neutral Scale)	27	28.2 (SD: .980)	$T(5) =.-1.168, p = .137$
Passive sorting	65% correct	98.3% (SD: .02)	$T(5) = -8.265, p < .001$

a vertical alignment. In each trial, two stimuli were identical and one differed, either in shape, luminance (i.e., brightness), colour (red–green), or motion.

Stimuli for the shape discrimination task were two squares (3.2° × 3.2° of visual angle) and one rectangle (6.4° × 1.6° of visual angle, at start), resulting in different shapes with the same surface area (10.24 deg^2). After three correct responses, the difference between the squares and rectangle became smaller.

Stimuli for the luminance discrimination task were three squares of the same size (3.2° × 3.2° of visual angle), one of which differed in brightness. At start, two of the stimuli were black (*xyY* = .304, .319, .480) and one was white (*xyY* = .318, .330, 105.33), or vice versa. After three correct responses, the Michelson contrast between the stimuli became smaller, resulting in more greyish stimuli. It is important to note that the odd stimulus could either be a darker or a lighter square.

Stimuli for the colour discrimination task were three squares of the same size (3.2° × 3.2° of visual angle), one of which differed in colour (red–green). The two stimuli with the same colour differed in luminance, to rule out the possibility that the task could be done based on luminance differences between the two different colours alone. Two of the stimuli could be green (*xyY* coordinates = .287, .585, randomly varied) and one could be red (*xyY* coordinates = .622, .339, randomly varied), or vice versa. After three correct responses, the colour contrast between the stimuli became smaller, resulting in more yellowish stimuli. It is important to note that the odd stimulus could either be a more reddish or a more greenish square.

Stimuli for the motion discrimination task were three squares of the same size (3.2° × 3.2°), through which a more or less coherent field of moving dots could be perceived. The size of the dots was .078° (~4.5 arcmin) and each square contained 234 moving dots. At start, 100% of the dots in two of the stimuli were moving in one direction (left or right) and in the third, dots were moving in the opposite direction. After three correct responses, motion coherence was reduced by 50% (i.e., 50% of the dots were coherently moving in one direction and the rest was randomly moving throughout the stimulus square). The speed of all moving dots was 1.32° per second, regardless of the direction of motion. It is important to note that the (coherent) dots in the odd stimulus could either be moving leftwards or rightwards.

Each test consisted of 45 trials and the odd-one-out had to be indicated via a button response box with three buttons, corresponding to the three locations on the monitor. After three consecutive correct responses, the differences between the stimuli became 50% smaller, resulting in more similar stimuli, and after an incorrect response, the differences between the stimuli became 50% larger (3-down-1-up staircase). With this procedure we are able to derive reliable thresholds per visual-sensory cue. The thresholds of LZ and 20 healthy controls (mean age: 34.6, SD: 11.3; all had normal or corrected to normal vision) are presented in Table 2.

4.2. *Results and discussion*

To compare the thresholds of LZ to the mean thresholds of the control group, we used Crawford and Garthwaite's (2002) significance test on differences between an individual's score and the control sample. As can be seen in Table 2, all thresholds of LZ fell within the normal range of the control participants. It should be noted that the mean age of the control group is lower than the age of LZ. However, her performance is within the range of this group. Even though it can be expected that the thresholds of an *age-matched* control group would be different, the expected thresholds for this group would probably be higher instead of lower, and threshold for controls is already higher than that of LZ in 2 out of 4 comparisons.

Interestingly, LZ could not verbalise whether the odd-one-out stimulus was brighter or darker than the other two stimuli in the luminance discrimination test, despite her normal luminance discrimination performance. Therefore, we conclude that she cannot discriminate the sign in contrast comparisons. These findings suggest specific problems with brightness *recognition* despite intact visuo-sensory processing of the primary visual cues.

5. Experiment 3: brightness recognition

5.1. *Method and procedure*

In order to directly test LZ's ability to detect whether lights are switched on or off, we designed an ecologically valid testing procedure in which LZ had to report a number corresponding to the brightness of the interior lighting. The experiment was carried out in a room with dimmed ambient light. In the first

Table 2 – Overview of the thresholds (ranging from 0 to 1) of LZ and healthy controls (+SEM) per visual primitive (shape, luminance, hue, motion)

	Threshold LZ	Threshold healthy controls	Significance (one-tailed probability)
Shape	.0760 *.24° × .22°*	.0477 (SEM .0056) *.15° × .14°*	T(19) = 1.392, *p* = .088
Luminance	.0662 *.141 Michelson contrast*	.0688 (SEM .0133) *.147 Michelson contrast*	T(19) = −.0123, *p* = .452
Colour	.0265 *xy red: .419, .428* *xy green: .410, .488*	.0300 (SEM .0067) *xy red: .427, .428* *xy green: .401, .502*	T(19) = −.172, *p* = .433
Motion	.2127 *21.27% coherent motion*	.1963 (SEM .0291) *19.63% coherent motion*	T(19) = .809, *p* = .213

part of the experiment, the intensity of the overhead lighting could be changed in five equal steps, ranging from 0 (light switched off completely) to 4 (light switched on completely). We first familiarised her with the response procedure. Next, we presented her five times with each different lighting condition in a random order. In between trials, she was blindfolded. On each trial, she was asked to rate the lighting intensity. She was free to look around and inspect the lights, room, reflections of light on objects, etc. while doing so. In the second part of the experiment, the overhead lighting was either completely switched off or completely switched on, both presented 10 times (in random order). In between trials, she was again blindfolded.

5.2. Results and discussion

The data of LZ were compared to a group of 6 age-matched controls (mean age: 64, SD: 4.8; all had normal or corrected to normal vision).[2] In order to analyse her performance, we calculated a distance effect for each trial: the difference between the actual position and the reported position. In the first part of the experiment she misjudged the brightness by a mean distance of 1.72 steps, which is not different from chance (1.6). LZ was very poor on this test: she often claimed that the light was completely switched on when actually it was switched off and vice versa. The mean distance effect of the age-matched controls was .053 steps (SD .2), at least an order of magnitude lower than that of LZ. Most of the errors made by the age-matched controls were made for levels ‘2’ and ‘3’. The results are shown in Table 3. In the second part of the experiment, LZ again misjudged the brightness and claimed that the lights were switched off when actually they were switched on completely in 60% of the trials (6/10 errors) and claimed that the lights were switched on when actually they were switched off completely in 40% of the trials (4/10 errors). The overall score of 5/10 is precisely at chance. Note that during each trial LZ had the opportunity to inspect the room from where she was seated. She frequently took this opportunity and looked around and even up to the halogen spot light(s) in the ceiling that provided the light needed for the different luminance levels. Even in these instances she could not discriminate between the lights switched completely on versus completely off (a ‘Source’ luminance difference of more than 250 cd/m^2; see Table 3). We thus conclude that LZ is unable to judge differences in brightness levels. We suggest that this inability to correctly judge these differences is a ‘labelling’ problem, e.g., being able to actually see the differences (see also Experiment 2), but being unable to apply the adequate labels (i.e., dark, bright/light) to changing lightness. It is important to note, that during this experiment, there was always a considerable amount of ambient light, so LZ never sat in complete darkness. In a different, informal test, we gave LZ the opportunity to actively switch on a desk light under different lighting conditions (complete darkness, dim light, and ambient light). During complete darkness, she always switched on the desk light. This shows that the absence of visual information allows her to correctly infer that the overhead light is off. However, with some visual information present, lightness recognition becomes difficult.

6. Experiment 4: inversion discrimination

6.1. Method and procedure

Brightness is the basis for the detection of inversion or photographic negatives. Normal observers find it extremely easy to discriminate normal greyscale images from negatives. We investigated LZ’s ability to do so in an experiment in which 48 images of objects were shown in greyscale as well as inverted greyscale. The images were high frequency living and non-living items presented on a black background. The images were presented centrally on a 17-inch monitor with a refresh rate of 60 Hz. The images remained on the screen until a response was given. Participants were told that they would be shown images of objects, which could either be normal greyscale images or inverted greyscale images. The latter resembled the negatives of photographs (see Fig. 2). They were shown examples first, to make sure that it was clear what a normal greyscale and an inverted greyscale image looked like. Responses could be made by pressing the ‘g’ key for a normal greyscale image and the ‘f’ key for an inverted greyscale image.

6.2. Results and discussion

The data of LZ were compared to a group of 6 age-matched controls (mean age: 64, SD: 4.8; all had normal or corrected to normal vision).

LZ’s performance on this discrimination test did not exceed chance level with 24 out of 48 answers correct (50%). The age-matched controls performed significantly better than LZ: 81.8% (Standard Error of the Mean – SEM = 2.14). The Crawford and Garthwaite’s (2002) significance test on differences between individual’s score and control sample showed that LZ’s performance was significantly worse than that of the age-matched control participants [$t(5) = -13.291$, $p < .001$]. Therefore, LZ is clearly unable to discriminate between normal and inverted greyscale images. She was able to name all objects that were presented in greyscale, so her poor performance on this task could not result from unfamiliarity with the objects shown.

7. Experiment 5: object–lightness associations

7.1. Method and procedure

In order to investigate object–lightness associations, LZ was presented with 9 questions about the lightness of objects [e.g.,

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[2] It is important to note that although the controls were tested in a different room with a different dimmer, they were tested with the same ecologically valid procedure (five equal steps of dimmed ambient light provided by halogen spots in the ceiling, in a room with dimmed ambient light). The exact levels of ambient light were lower for controls than for LZ, yet the range of levels was comparable, as were the luminance levels of the light Source and Table (see Table 3). Both LZ and controls were allowed to use the Source light, Ambient light (reflections), and Table light reflections for their judgements.

Table 3 – Overview of responses and percentages correct for LZ and controls in the brightness recognition task. Luminance values were measured with a handheld spot single lens reflex (SLR) tristimulus colorimeter (Konica Minolta, model CS-100A). Ambient luminance reflects the average of horizontal measurements along the four cardinal axes of the room from participant's seat, while Source luminance and Table luminance values were measured by aiming the colorimeter as precisely as possible at the halogen spot above the table at which the participant was seated and the table top, respectively

	Level	Luminance Levels [cd/m^2 (SD)]			LZ's response	% Correct
		Ambient	Source	Table		
LZ	0	14.25 (4.86)	8.9	3.8	0/0/4/4/0	60%
	1	17.30 (4.2)	107	6.9	3/4/4/4/0	0%
	2	18.43 (4.1)	169	9.15	4/2/0/0/4	20%
	3	19.33 (5.4)	250	12.8	4/4/0/4/4	0%
	4	20.35 (5.7)	262	22.8	4/0/4/0/4	60%
	Distance				1.720 (SD 1.4)	
Controls	0	5.66 (5.21)	9.0	4.3		100%
	1	7.82 (3.76)	119	6.2		100%
	2	10.51 (2.91)	152	9.7		83% (SD 13.7)
	3	12.22 (2.75)	206	12.2		90% (SD 10)
	4	13.51 (1.91)	232	28.1		100%
	Distance				.053 (SD .2)	

"Is a cigar dark or light?", "Are peas dark or light?" (see de Vreese, 1991)].

7.2. *Results and discussion*

The data of LZ were compared to a group of 6 age-matched controls (mean age: 64, SD: 4.8; all had normal or corrected to normal vision).

LZ answered 66.7% of the questions correctly, whereas the controls performed significantly better [98.1%; $t(5) = -4.915$, $p < .005$].[3] Although LZ is not fully impaired on verbal object–lightness associations, we conclude that LZ at least shows some difficulties with associating lightness to objects, or vice versa.

8. Experiment 6: brightness induction

8.1. *Method and procedure*

For investigating brightness induction (or 'simultaneous contrast') in LZ, we presented her and 6 age-matched controls (mean age: 64, SD: 4.8; all had normal or corrected to normal vision) with 18 pairs of stimuli, consisting of 2 grey squares surrounded by either darker or brighter (achromatic) surrounds. Normally, a grey stimulus on a light grey background is perceived as being darker, compared to the same grey stimulus on a darker grey background (e.g., Cornsweet, 1970). In this task, both LZ and the control participants had to indicate whether the two grey squares were the same or different, and second, if different, which one was brighter or darker. There were 3 conditions: first, identical grey squares with two different backgrounds (one darker than the square, one brighter; brightness induction); second, different grey squares with two different backgrounds (one darker than the square, one brighter; different squares appear identical); and third, identical squares with identical backgrounds (control condition).

Hit rate (HR), false alarm rate (FAR), *d* prime (d'), and bias (β) were calculated per participant and compared using Crawford and Garthwaite's (2002) significance test on differences between individual's score and control sample.

8.2. *Results and discussion*

Table 4 shows the response in each of the trials for both LZ and control participants. Calculated HR was higher for LZ (.8) compared to controls (.45) [$t(5) = 3.24$, $p < .05$], whereas FAR was not significantly lower [.25 *vs* .40; $t(5) = -.52$, $p = .31$]. Moreover, d' was higher for LZ (1.52) compared to controls (.14), indicating that discriminability was much better in LZ than in controls [$t(5) = 3.12$, $p < .05$], whereas β was comparable [$t(5) = -.45$, $p = .32$], indicating that her bias in responding was similar to the bias of controls. In other words, LZ was very good in detecting the actual differences in brightness, and was much less influenced by the surrounding background

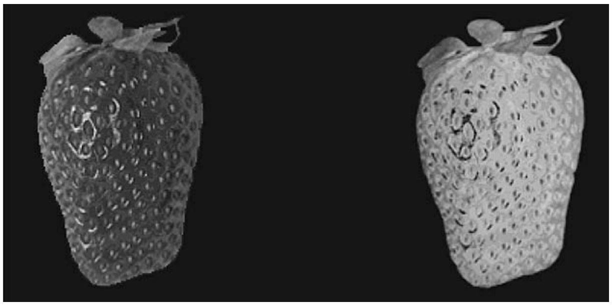

Fig. 2 – Examples of the stimuli used in the inversion discrimination task.

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[3] One control participant had a score of 8 correct answers out of 9, whereas the performance of the other controls was flawless. LZ had a score of 6 correct answers out of 9.

than controls were. This suggests that brightness induction, caused by the contrast between stimulus and its background appears to involve some higher-order component at the level of brightness recognition (rather than low-level interactions only; see also Adelson, 1993; de Weert and van Kruysbergen, 1997). In addition, when the squares were of similar luminance, but were (perceived to be) of different greys by the controls, they were able to indicate which of the two squares appeared brighter or darker. LZ, on the contrary, could not indicate which of the two squares appeared brighter or darker when she perceived them to be of different greys. This is in line with our findings of Experiment 2, in which she was also able to indicate the odd-one-out in the luminance discrimination task, but not whether it was brighter or darker compared to the other two.

9. Experiment 7: colour recognition

9.1. *Method and procedure*

In order to investigate the specificity of the brightness recognition problems, we investigated LZ’s performance on standard tests for colour recognition (van Zandvoort et al., 2007): colour naming (analogue to *naming* the darker or brighter of the squares in the brightness condition of Experiment 2), colour categorisation (active and passive; analogue to the brightness sorting tasks in Experiment 1), object–colour verification (analogue to Experiment 4), and verbal object–colour associations (analogue to Experiment 5).

The colour naming task entitled 7 different coloured squares (red, green, blue, yellow, orange, pink, purple) were presented on a monitor for 100 msec (50% of the trials) or 150 msec (50% of the trials) on a 17-inch monitor (60 Hz). The coloured squares were presented sequentially, in a random order. Each colour was presented 4 times (28 squares to be named in total). LZ was asked to name the colours as accurately and fast as possible. The relatively short presentation durations were chosen since colour agnosics may use idiosyncratic strategies to infer the colour of objects. For example, patients might compare for instance the surface properties of a presented object with that of an object with a known surface colour of (for example the shirt they wear; van Zandvoort et al., 2007).

Table 4 – Overview of responses for LZ and the healthy controls in the brightness induction task

Item (type)	Response of LZ	Response of controls (%)
1 (a)[a]	Same	Different (83.3%)
2 (b)	Same	Different (100%)
3 (b)	Different	Different (83.3%)
4 (c)	Same	Same (100%)
5 (b)	Different	Different (50%)
6 (b)	Different	Different (50%)
7 (b)	Different	Different (100%)
8 (a)	Same	Different (66.7%)
9 (a)	Same	Different (66.7%)
10 (a)	Different	Different (66.7%)
11 (c)	Same	Same (83.3%)
12 (b)	Different	Same (83.3%)
13 (a)	Same	Different (100%)
14 (a)	Same	Different (66.7%)
15 (b)	Same	Same (66.7%)
16 (b)	Different	Different (50%)
17 (b)	Different	Same (83.3)
18 (a)	Same	Different (100%)

[a] a = similar squares, different backgrounds; b = different squares, different backgrounds; c = similar squares, similar backgrounds.

Colour categorisation was measured in two different ways: first, by grouping coloured tokens (active sorting); second, by indicating which of two arrays of coloured squares is sorted (passive sorting). For the active sorting task, there were 10 tokens each in one of 5 different colours (white, red, green, blue, and yellow). The task was to make separate categories per colour. For the passive sorting task, two arrays of coloured squares were presented at the same time, one of which was sorted. LZ was asked to indicate which of the two was neatly sorted from one colour to another (e.g., from red to green, with orange and yellow in between). The colours approached equiluminance, thus sorting on the basis of luminance was not possible. In addition, small bars were placed in between the coloured squares in order to ensure that colour contrast could not be used as a direct sorting cue.

The object–colour verification entailed 40 line drawings of objects presented in both an appropriate and inappropriate colour (e.g., red strawberry *vs* blue strawberry). The line drawings were presented sequentially and remained on the monitor (17-inch monitor, 60 Hz) until a response was given. LZ was asked to indicate as accurately and fast as possible whether the line drawings were depicted in a correct colour or not. She was told to press the ‘g’ key when a line drawing was correctly coloured (e.g., red strawberry) and the ‘f’ key when a line drawing was incorrectly coloured (e.g., blue strawberry).

In the verbal object–colour association task, 9 questions about the colours of objects were asked (e.g., “What is the colour of a banana?” or “What is the colour of a strawberry?”).

9.2. *Results and discussion*

The data of LZ were compared to a group of 6 age-matched controls (mean age: 64, SD: 4.8; all had normal or corrected to normal vision).

LZ was perfectly able to name colours, categorise colours, indicate whether line drawings were depicted in a correct or incorrect colour, and answer questions about object–colour associations (see Table 5).

For comparing the performance of LZ to the mean performance of the control group, we again used Crawford and Garthwaite’s (2002) significance test on differences between an individual’s score and the control sample. As can be seen in Table 5, performance of LZ on all tasks fell within the normal range of the age-matched control participants. In other words, there are no indications for additional colour recognition impairments. As she also showed thresholds comparable to control participants on the colour discrimination test (Experiment 2) and was able to name the line drawings of the Boston Naming Task and the images of objects of the luminance inversion discrimination, we suggest that LZ’s difficulties with brightness recognition are selective.

Table 5 – Performance of LZ on the colour recognition tasks

	% Correct LZ	% Correct healthy controls	Significance (one-tailed probability)
Naming	100	100 (SD 0)	n.a.
Sorting (active)	100	100 (SD 0)	n.a.
Sorting (passive)	100	97.5 (SD 5)	$T(5) = .463$, $p = .331$
Verify object colour	97.5	99.1 (SD 1.86)	$T(5) = -.796$, $p = .231$
Verbal object–colour associations	100	100 (SD 0)	n.a.

10. Discussion

Visual agnosia is a deficit in higher-order recognition. It may affect all visual categories, but in selective cases, it may be restricted to stimulus categories (e.g., objects, faces) or feature domains (e.g., shape, colour). By definition, elementary visual processes, language and memory must be intact.

In this study, we describe a patient LZ, with a remarkable difficulty in recognising different brightness levels. For example, she has severe problems with indicating whether the light in a room is switched on or off (Experiment 3) and verifying whether images of objects are presented in normal greyscale or inverted greyscale (Experiment 4). Notwithstanding her pronounced problems with brightness interpretation, she is perfectly able to discriminate between stimuli of different bright- and darkness levels. Her normal VA and CS, along with normal performance in discriminating differences in shape, colour, and motion, *as well as luminance* (Experiments 1 and 2), rules out an explanation in terms of deficits at the early stages of perceptual processing of both *brightness* (odd-one-out task) and *lightness* (Munsell Neutral Value Scale). To investigate the specificity of the problems with brightness judgements (e.g., the problems with brightness judgements might extend to colour), we also used specific tests regularly used for diagnosing colour agnosia (Experiment 7) and found that she was perfectly able to name and sort colour, and verify coloured objects. King-Smith et al. (1984) described a number of cases of selective damage to achromatic processes. None of these cases, however, resemble the case reported here in that all these prior cases had deficits in early achromatic processing (e.g., poor luminance CS relative to chromatic CS), whereas LZ has no deficits in the early stages of perceptual processing. The present data strongly suggest that brightness is represented independently of colour and that this representation is itself separate from the representation of luminance contrast that might contribute to form perception.

The pattern of intact and impaired visual processes in LZ is reminiscent of colour agnosia. A clinical description of colour agnosia is that it is a selective impairment in the recognition of colour that cannot be explained by visual-sensory, memory or language deficits (Klein and Stack, 1953; Beauvois and Saillant, 1985; van Zandvoort et al., 2007). It is selective in that it only affects colour, while the recognition of other primary visual cues, such as motion and shape, or higher-order visual categories, such as objects and faces, remain unaffected.

With respect to selectivity of LZ's impairment with bright- and darkness, we showed that her performance on the *colour* recognition tests was flawless: she made no errors on the colour naming, colour sorting, and verifying object–colour tests. On equivalent tests for brightness recognition, however, she was unable to (i) indicate bright and dark stimuli, (ii) indicate whether brightness level was increased or decreased, (iii) indicate whether an array of stimuli was sorted or not with respect to brightness (i.e., poor passive sorting and quite accurate, but excessively slow active sorting); and (iv) verify the correct luminance format of images of objects. LZ did not have problems with *recognising* objects; her performance on the Boston naming task was normal and she was also able to name objects or point to objects named by the experimenter.

The bright- and darkness recognition problems in LZ appear to result from problems with associating a (normal) percept with a visual representation stored in memory: her normal thresholds for luminance (contrast) as well as other primitives indicate adequate functioning at the perceptual level, yet she appears to have problems with comparing a percept to semantic knowledge about brightness or darkness in memory.

Although the simple framework of connecting visual perception to semantic knowledge has been proven to be useful for categorising visual disorders, it has not gone uncontested. The concept of associative agnosia has been doubted by some neuropsychologists, who claim that underlying perceptual deficits can always be found if sensitive enough measures are used (Farah, 1990; Delvenne et al., 2004). It was Bay (1953) who claimed that the concept of associative agnosia (Lissauer, 1890) was ill conceived. In Bay's view (see also Campion and Latto, 1985), these stimulus-specific recognition disorders resulted from low-level visual impairments. This suggestion has been refuted by Ettlinger et al. (1957) and by De Haan et al. (1995) who claimed that although some patients with a recognition deficit may have sensory impairments, other patients who do not experience recognition problems can show equal or worse sensory impairments. Therefore, sensory status alone could not explain the presence or absence of recognition disorders.

We believe our measurements of visuo-sensory functions in LZ are indeed very sensitive, by selectively measuring thresholds per visual primitive (shape, luminance, colour, motion) without finding any differences when comparing LZ's thresholds to those of a group of healthy controls. This is analogous to our earlier findings in colour agnosia (van Zandvoort et al., 2007).

The present findings suggest that recognition deficits can occur for a single visual feature. So far, no case of "brightness agnosia" had been reported in the literature. It might thus be possible that, next to shape and colour, other visual features can also selectively become impaired, such as recognition of motion- (e.g., left/right, or up/down, or slow/fast) or texture-properties.

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