Detecting gradual visual changes in colour and brightness agnosia: a double dissociation

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Two patients, one with colour agnosia and one with brightness agnosia, performed a task that required the detection of gradual temporal changes in colour and brightness. The results for these patients, who showed an average or an above-average performance on several tasks designed to test low-level colour and luminance (contrast) perception in the spatial domain, yielded a double dissociation; the brightness agnosic patient was within the normal range for the coloured stimuli, but much slower to detect brightness differences, whereas the colour agnosic patient was within the normal range for the achromatic stimuli, but much slower for the coloured stimuli. These results suggest that a modality-specific impairment in the detection of gradual temporal changes might be related to, if not underlie, the phenomenon of visual agnosia. *NeuroReport* **22:175–180 © 2011 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Agnosia is clinically defined as the inability to recognize, for example, objects, persons, colours, in the absence of visuosensory, memory or language deficits [1,2]. Recently, we had the unique opportunity to thoroughly study the visual capacities of two patients suffering from impairments in the recognition and appreciation of either colour (patient M.A.H. with colour agnosia) [3] or brightness (patient L.Z. with brightness agnosia) [4]). We found that, neither patient showed any impairment in perceiving or discriminating low-level visual features (shape, colour, luminance, hue and motion) when these features could be directly (spatially) compared; all discrimination thresholds were within the normal range.

Subsequently, both a colour and a greyscale categorization task (i.e. the Farnsworth–Munsell 100-hue test and the Munsell Neutral Value Scale, respectively) were performed, in which either coloured or greyscale tokens were to be sorted. Both patients showed normal categorization behaviour for their unimpaired visual feature. However, M.A.H. moved each colour token along the formation, just until he found the most perfect match, whereas L.Z. showed the same behaviour but for the greyscale tokens. This idiosyncratic strategy resulted in an anomalously long time needed to finish the task, yet their scores were fairly high (within normal range; in both mentioned tests, the total score is considered to be the parameter of interest). In other words, the comparisons could be done, but were purely based on direct, local contrasts in either colour or luminance. However, when two tokens could not be directly and locally compared (as in a passive-sorting task, in which arrays of chromatic or achromatic squares were presented and participants had to indicate whether they were sorted or not, without being able to actively move the stimuli next to one another), they failed at the task in the dimension of their recognition impairment. This discrepancy suggests that visual information specific to their impaired primitive cannot be retained in 'visual working memory' and used for spatial comparisons that cannot be made directly and locally. This notion also fits well with an earlier (unpublished) observation that M.A.H. was fairly good in a spatial comparison task (same–different judgment) when both visual stimuli were directly adjoining, but impaired when relatively large (spatial) gaps were introduced between both stimuli.

In this study, the evaluation of colour and luminance over time will be investigated in both patients. Even though spatial and temporal processings are often considered to be largely independent, temporal processing (i.e. comparisons between two subsequent visual stimuli) might cause the described impairments in visual agnosia when both stimuli cannot be directly compared.

Methods

Participants

Two patients, M.A.H. and L.Z., and 10 controls [mean age: 50.10 years, standard deviation (SD): 13.48 years; five men] participated in this study. All participants had normal or corrected-to-normal visual acuity and reported no colour blindness, which was confirmed with the Ishihara test for colour blindness [5].

Both patients have been reported in detail elsewhere (M.A.H.: [3]; L.Z.: [4]), and will only be briefly summarized in this study.

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Data included in this study were obtained in compliance with the Helsinki Declaration.

M.A.H.

At the time of testing, M.A.H. was a 45-year-old right-handed male, who suffered from developmental agnosia ([3,6], for more details and scan). We had the unique opportunity to investigate most levels of M.A.H.'s colour processing: colour discrimination, categorization, object colour recognition, object colour recall, colour naming and pointing to named colours. Although colour discrimination seemed to be intact (Farnsworth–Munsell [7] 100-hue test score: 44; note that he needed an anomalous amount of time to sort the hues, and was never satisfied with the result) [3], all other tested levels of colour processing were severely impaired [6,8]. These impairments were very specific, as M.A.H. did not show any impairment for other visual primitives (shapes, luminance) or objects or faces.

L.Z.

At the time of testing, L.Z. was a 66-year-old right-handed female, who suffered a subarachnoid haemorrhage that resulted in a large infarct of the right hemisphere involving the parietal, temporal and occipital lobes with extensions into the frontal region (for more details and scan see [4]). By the time she was examined in our laboratory for the first time (July 2006), she showed a normal visual acuity, contrast sensitivity, low-level visual perception (shape, colour, luminance and motion), language and memory, and she showed a moderate left-sided visual neglect. In addition, she showed a remarkable difficulty in interpreting and recognizing different brightness levels (verifying normal or contrast reversed greyscale images, naming, passive sorting). Not withstanding her pronounced problems with brightness interpretation, her score on the active sorting task (Munsell Neutral Value Scale; Munsell Colour Services, New Windsor, New York, USA) was normal, although it was based on (direct) local comparisons and, therefore, took an anomalously long time.

Apparatus

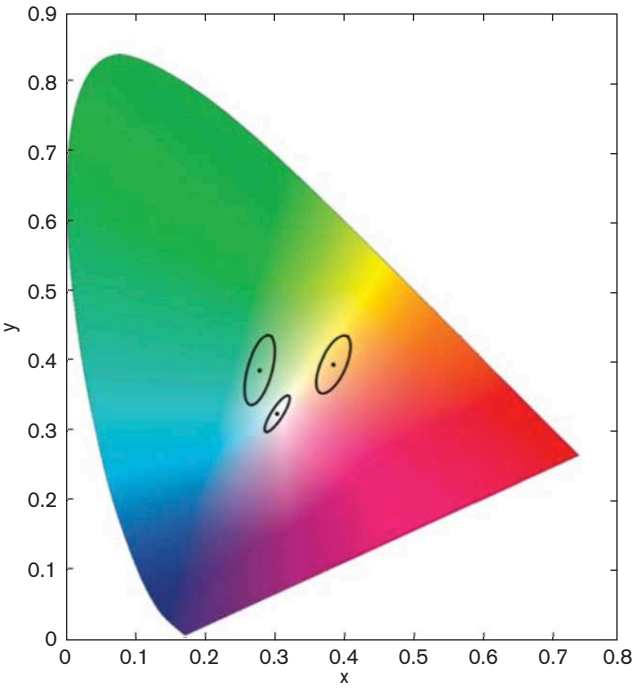
All stimuli were generated using MATLAB (Mathworks, Massachusetts, USA) in conjunction with the Psychophysics Toolbox [9,10], and were presented on a calibrated laCie 22-inch monitor (75 Hz, 1024×768; LaCie Benelux, Harmelen, The Netherlands). CIE values of the red, green and blue phosphors were measured using a hand-held spot SLR tristimulus colorimeter (Konica Minolta, model CS-100A, Nieuwegein, The Netherlands). In all conditions, participants viewed the monitor binocularly from a distance of 57 cm, which was controlled for with a chin and forehead rest.

Stimuli and procedure

Participants were tested individually in a quiet darkened room. There were two orthogonal main conditions in the experiment, a colour condition in which the luminance of the stimulus remained the same, but the colour changed, and a luminance condition, in which only the luminance of the stimulus changed.

For the colour condition, the stimuli were uniformly coloured discs (5.1° of visual angle in diameter), presented on a grey background (xyY value: 0.312 0.329 21.6). The colour of the discs was chosen from three different MacAdam ellipses [11,12] [see Fig. 1; central points of the ellipses (xyY values): first, 0.385 0.393 57; second, 0.305 0.323 57; and third, 0.280 0.385 57]. [MacAdam ellipses were chosen, as all hues on an ellipse have the same perceptual distance in colour space (in just-noticeable differences; JNDs) from the central point of the ellipse. Colour changes are, therefore, perceptually comparable, irrespective of the start point. This is equivalent to a circle around the white midpoint in Luv space] The ellipses were chosen to encompass several colour categories. Of note, the grey background on which the stimuli are presented is not the centre of one of the ellipses. Two radii, defining the size of the ellipses were used, 12 and 24 JNDs. Twelve trials were presented for each ellipse (six with the 12 JND radius, and six with the 24 JND radius), resulting in a total of 36 trials.

Fig. 1



The MacAdam ellipses used. Such an ellipse [with a radius of 1 just-noticeable difference (JND)] defines the region of a chromaticity diagram, within which all colours are indistinguishable to the average human eye, from the colour at the centre of the ellipse (see Wyszecki and Stiles [12]). In this experiment, three ellipses were chosen. The luminance was, therefore, kept at one level for all stimuli. Only the ellipses with the 12 JND radii are shown.

Each ellipse was divided into 200 equal steps. The colour of the disc changed with three steps per second (one step every 333 ms). The starting point on the ellipse and the direction of change was randomized between trials. Participants were asked to press the space bar on the computer keyboard as soon as they perceived that the disc had changed. Of note, the only possible change was a colour change, yet the participants were not explicitly instructed on the type of change, as this would have been an uninformative instruction for M.A.H.

For the luminance condition, the otherwise identical stimuli were uniform grey discs, presented on a grey background (xyY value: 0.312 0.329 21.6). The luminance values of the grey discs ranged from 9.338 to 54.48 cd/m^2, divided into 100 more-or-less equal steps. The luminance of the disc changed gradually, with three steps per second. Again, the starting luminance and changing direction were randomized between trials, and participants were again asked to press the spacebar as soon as a change was detected. If the maximum or minimum luminance values were reached before a change was detected, the direction of luminance change was reversed.

Data analyses

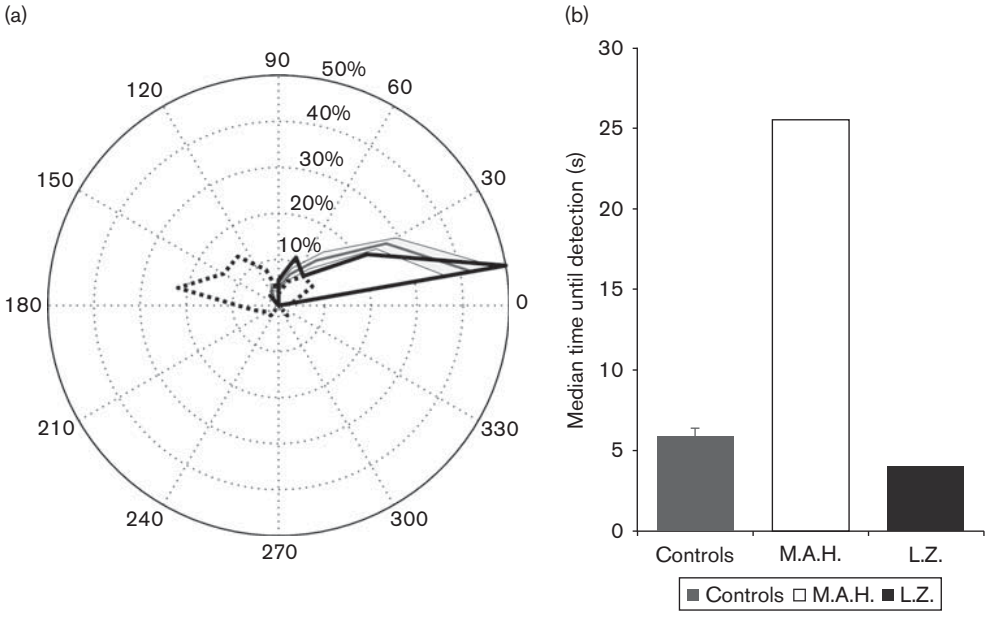
In both experiments, start RGB values, end RGB values and response times were recorded. Difference scores (in degrees revolution along the ellipse for the colour condition, and in cd/m^2 for the luminance condition) between end-point and starting-point values were calculated. Crawford and Garthwaite's [13] significance test on differences between an individual's score and a control sample was used to analyse the data. Response times were used as an extra indication of the difference between the end-point and starting-point values, especially when more than 200 steps (one full revolution) would be needed for a colour change to be detected, or when the luminance change direction would reverse within a single trial.

As an extra control for the effect of our stimulus parameters, we checked whether the start RGB correlated with the magnitude of the responses (degree revolution along the MacAdam ellipse, cd/m^2, or response time). Although start RGB was randomized between trials it might have affected our results, especially in the luminance condition. Herein the (physical) luminance scale was more-or-less linear, which resulted in perceptually nonlinear brightness scale. However, no significant correlation was found between start RGB and response magnitudes for any condition, for any of the participants.

Results and discussion of colour experiment

As there were no differences between the two ellipse radii (12 and 24 JNDs) and the three MacAdam ellipses used for the controls, the data were collapsed across those factors. It is immediately apparent from Fig. 2a that a change was reported by controls in most cases when the colour change was less than 20° from the starting point on the ellipse, with a mean angular distance on the ellipse of 35° (SD: 11°). M.A.H., in contrast, responded most often

Fig. 2



(a) The percentage of trials in which a colour change was detected within 20° bins (18 bins in total of 360° on MacAdam ellipse) for M.A.H. (dotted line), L.Z. (black line), and the controls (grey line). Shaded grey area shows the control date ± 1 standard error of the mean. (b) The median time until the detection of the gradual colour change (+ 1 standard error of the mean for the controls).

when the disc had changed in colour between 160 and 180° from the starting point; in other words, when the colour of the disc almost reached a value on the opposite side of the MacAdam ellipse (i.e. had made almost half a revolution). The mean angular distance on the ellipse of M.A.H.'s responses was 131°. The controls were much better in detecting these temporal colour changes than M.A.H. was [$t(9) = 8.287$, $P < 0.001$]. In contrast, L.Z. responded most often within 0–20° from the starting point, and the mean angular distance on the ellipse for L.Z. was 31°. Not surprisingly, her performance of detecting temporal colour changes was within the normal range of the controls [$t(9) = -0.325$, $P = 0.754$].

Analysis of the response time (see Fig. 2b) shows a median response time for controls of 5.9 s (SD: 0.52 s), well below that of M.A.H. [25.5 s; $t(9) = 11.487$, $P < 0.001$]. L.Z.'s median response time, of 4.0 s fell within the normal range of the controls [$t(9) = -1.091$, $P = 0.304$].

In summary, the performance of the colour agnosic patient (M.A.H.) on this task was impaired, whereas the performance of the brightness agnosic patient was comparable with that of healthy controls [of note, faster colour-change condition (12 steps per second) was also included. The results for this condition were similar to the slower colour change condition, but much noisier. The responses of the controls and L.Z. were already more variable, whereas M.A.H.'s often let more than a full revolution of the ellipse pass before indicating that the disc had changed, thereby confounding the analysis].

Results and discussion of luminance experiment

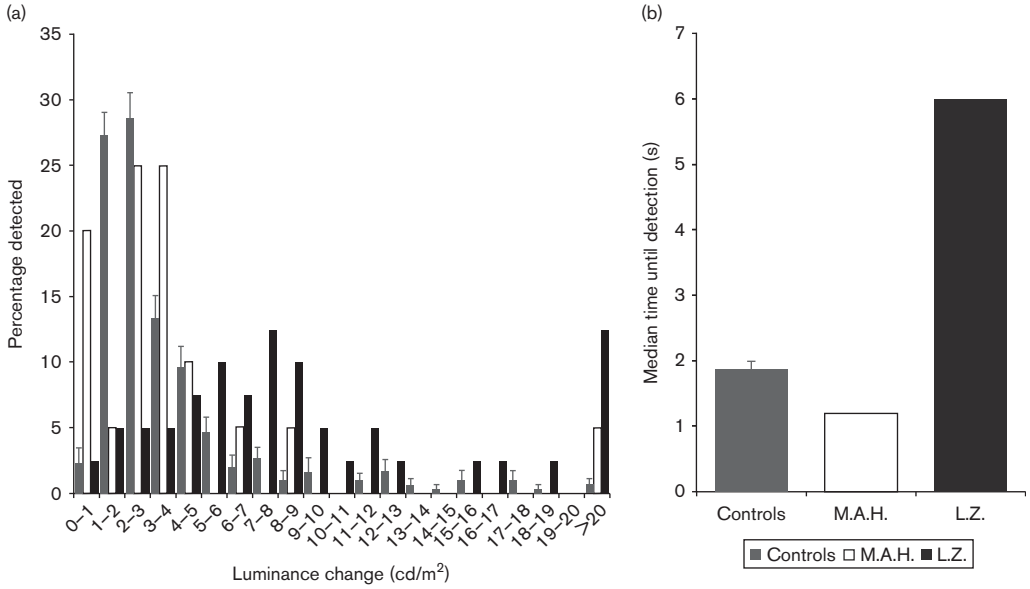
Changes were detected by controls (see Fig. 3a) most often before the stimulus had changed to 3 cd/m^2 in luminance, with a mean luminance difference between the end-point and the starting-point of 3.8 cd/m^2 (SD: 1.23 cd/m^2). M.A.H. needed comparable luminance changes to detect them [mean luminance difference 4.2 cd/m^2; $t(9) = 0.276$, $P = 0.789$]. In contrast, L.Z. needed (on average) a luminance difference of 10.5 cd/m^2 to detect a change, a luminance difference much larger than that for controls [$t(9) = 5.138$, $P = 0.001$].

Analysis of the response time (see Fig. 3b) shows the median response time to be 1.8 s (SD: 0.36 s) for controls. M.A.H.'s median response time (1.19 s) fell within the normal range of the controls [$t(9) = -1.838$, $P = 0.099$].The median response time (6.0 s) of L.Z., however, was much longer than that of the controls [$t(9) = 11.056$, $P < 0.001$]. Hence, in this (luminance) experiment, the performance of the colour agnosic patient was comparable with that of controls, whereas the performance of the brightness agnosic patient was impaired.

General discussion and conclusion

In this study, temporal comparisons of colour and luminance were investigated in colour and brightness agnosia. The results showed that M.A.H., the patient with colour agnosia, showed an impairment in detecting gradual colour changes with intact ability to detect gradual luminance changes, whereas L.Z., the patient with brightness

Fig. 3



(a) An overview of the percentages-detected luminance changes (cd/m^2); (b) median time until the detection of the gradual luminance change. (Error bars show +1 standard error of the mean for the controls).

agnosia, showed the reversed pattern. For both patients, impairments in temporal processing of visual information were found to be very specific, namely in the exact visual primitive of their agnosia.

A possible explanation of these results might be related to visual 'working memory' processes (i.e. short-term visual representations). To detect changes between two successive fixations on an object, the visual image of the first fixation needs to be retained in visual 'working memory' (the visuospatial 'sketch path', one of the subsystems of the working memory; [14]), so the visual image from the second fixation can be compared with the first one. That this is not a trivial process for our brain is demonstrated by the phenomenon of change blindness with, for instance, the flicker paradigm, in which two images are presented in rapid succession with a blank interval in between [15]. One of the otherwise identical images can lack an entire salient object, but nevertheless, it can take seconds to minutes for the participants to detect such a change. In our experiment, stimuli were not as complex and did not contain many details, but the changes between successive frames were very subtle (in this sense more comparable with the gradual change blindness stimuli; e.g. [16]). Controls could easily, and relatively quickly determine whether the stimulus had changed or not. Our agnosic patients were perfectly able to do so as well, except, however, for the visual primitive related to their recognition impairment. This suggests that 'change blindness' might exist for specific visual features, which causes impairments in the recognition of that specific visual feature and not others.

Recently, Wallis *et al.* [17] showed that temporal associations aided in learning to generalize object representations across smooth changes in appearance, including changes brought about by changes in illumination that would affect perceived colour (and relative lightness) of the object, and as such are related to colour (and lightness) constancy processes [in the colour domain, constancy ensures that the perceived colour of objects remains to be relatively constant under varying illumination conditions (e.g. [18]). Analogously, anchoring-type theories of lightness perception (e.g. [19,20]) can be interpreted as explaining constancy mechanisms in the achromatic domain]. An impairment of such a temporal association mechanism might lead to problems in forming associations between objects and their surface properties (such as colour and relative lightness), thereby, deeming temporal associations crucial factors for typically 'what' stream relations [21]. A failure specific to colour constancy would prevent the development of boundaries of colour categories, which, in turn, would result in a deficit in detecting changes in colour, especially across colour categories. Analogously, such a constancy deficit might also underlie problems with recognizing lightness levels.

Interestingly, recent evidence suggests that working memory and visual constancy (i.e. stability) are related. Allen *et al.* [22] compared the degree of colour constancy between a group of individuals with a high and a low working memory capacity. They showed high working memory individuals to have better colour constancy than low working memory individuals, and interpreted this difference as a difference in the ability to maintain the colour representation over a prolonged delay period. In a similar vein for luminance information, 'anchoring' a luminance range [19,20] might still be relatively intact, but this anchor might not be adequately stored in the working memory.

In short, we propose that working memory impairments may lead to specific deficiencies in colour or lightness constancy, because an efficient representation of colour and lightness requires constant updating through visual 'memories'. Deficits in visual working memory would then (slowly) lead to a deficient representation of either colour or lightness (which in our experiment is equivalent to brightness; see [23]), thus explaining typical higher order impairments (e.g. naming and categorization) in these forms of agnosia. Of note, however, these proposed visual working memory impairments are specific to a single visual primitive, as both M.A.H. and L.Z. seemed to have full access to the representation of the unaffected primitive.

Riddoch *et al.* [24] stated that perceptual processing of objects leads to consistent updating of visual memories over time, so that these memories remain tuned to the visual properties of objects. A lack of input may, therefore, gradually result in a decline of (long-term) visual memory. On the basis of this data, however, the investigators would like to claim the converse, and argue that it is not a perceptual input that is impaired in our agnosic patients (i.e. both are able to indicate whether two adjoining colour or luminance stimuli are identical or not), but (short-term) visual working memory (i.e. an impairment in updating of short-term memories of a specific (surface) attribute over time).

Although many studies have measured processing of static visual primitives in clinical studies, studies into (integration) processes over time have been scarce, yet our results suggest that this may be a process that might be related to, if not underlie, visual agnosia. In particular, as low-level processing of static visual primitives seemed to be unaffected in both patients, even for the very visual primitive they had problems recognizing.

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