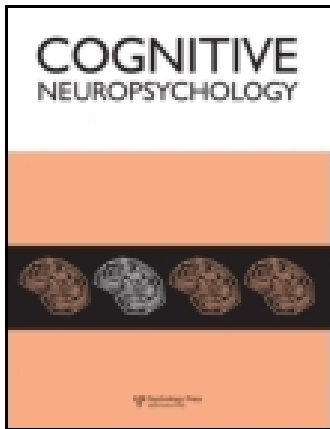


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Publisher: Routledge

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Cognitive Neuropsychology

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/pcgn20>

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Published online: 10 Apr 2007.

To cite this article: Tanja C. W. Nijboer, Maarten J. Van Der Smagt, Martine J. E. Van Zandvoort & Edward H. F. De Haan (2007) Colour agnosia impairs the recognition of natural but not of non-natural scenes, *Cognitive Neuropsychology*, 24:2, 152-161, DOI: [10.1080/02643290600989541](https://doi.org/10.1080/02643290600989541)

To link to this article: <http://dx.doi.org/10.1080/02643290600989541>

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Colour agnosia impairs the recognition of natural but not of non-natural scenes

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Scene recognition can be enhanced by appropriate colour information, yet the level of visual processing at which colour exerts its effects is still unclear. It has been suggested that colour supports low-level sensory processing, while others have claimed that colour information aids semantic categorization and recognition of objects and scenes. We investigated the effect of colour on scene recognition in a case of colour agnosia, M.A.H. In a scene identification task, participants had to name images of natural or non-natural scenes in six different formats. Irrespective of scene format, M.A.H. was much slower on the natural than on the non-natural scenes. As expected, neither M.A.H. nor control participants showed any difference in performance for the non-natural scenes. However, for the natural scenes, appropriate colour facilitated scene recognition in control participants (i.e., shorter reaction times), whereas M.A.H.'s performance did not differ across formats. Our data thus support the hypothesis that the effect of colour occurs at the level of learned associations.

INTRODUCTION

What is the function of colour vision? Subjectively, colour greatly enriches visual experience, but more importantly, colour plays an important role in pattern detection and object recognition, as colour is a very prominent property of objects. As a result, knowledge of object colour might help to recognize objects better, along with luminance boundaries, shading, texture, and contours (e.g., Livingstone & Hubel, 1987).

Colour information has been shown to improve object recognition. Coloured images of objects are recognized faster than achromatic images of the same objects (Biederman & Ju, 1988; Ostergaard & Davidoff, 1985),¹ but this only holds for certain types of objects (Humphrey, Goodale, Jakobson, & Servos, 1994; Tanaka & Presnell, 1999)—namely, objects that are usually strongly associated with a specific colour—that is, for which the colour is “diagnostic” (Tanaka & Presnell, 1999). Interestingly, colour has no influence on object

¹ Note, however, that Biederman and Ju (1988) also showed that using a mask eliminated this facilitatory effect of colour.

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Tanja Nijboer was supported by NWO Grant 051.02.080 of the Cognition Program of the Netherlands Organization for Scientific Research (NWO). Maarten van der Smagt was supported by the NWO Innovational Research Grant 451.02.094 (VENI scheme) of the Netherlands Organization for Scientific Research (NWO). We would like to thank M.A.H for his generous participation. We thank Jennifer Steeves and colleagues for making their elaborate stimulus set available to us. Also, we thank Ryota Kanai for useful discussion of many aspects of this article.

verification (Biederman & Ju, 1988; Ostergaard & Davidoff, 1985). Apparently, appropriate colour facilitates finding the correct name of an object in memory, whereas it does not influence the comparison of a given name with a shown object. Ostergaard and Davidoff (1985) suggested that objects are listed in semantic representation as a collection of physical attributes. One of these attributes is specific colour information. They claim that colour being an attribute in the lexicon makes it possible to prime linked object names in the same lexicon. This explains why colour facilitates object naming, but not object verification.

Recognition of objects high in colour diagnosticity (usually natural objects) is more affected by colour manipulations (e.g., incongruently coloured images) than recognition of objects low in colour diagnosticity (usually non-natural, man-made objects; Joseph & Proffitt, 1996; Price & Humphreys, 1989). When colour is not informative, object recognition appears to be based on other cues, such as shape and texture cues (Oliva & Schyns, 1997; Tanaka & Presnell, 1999).

Neuropsychological studies have shown that some brain-injured patients with impaired object recognition abilities demonstrate improved performance when identifying coloured images of objects compared to incongruently coloured or achromatic images (Humphrey et al., 1994; Mapelli & Behrmann, 1997). Humphrey et al. (1994) showed that colour facilitated object recognition in D.F., a patient with visual form agnosia. This patient has a profound deficit in object recognition on the basis of shape, size, and orientation, but a relatively spared ability to recognize objects on the basis of colour and texture (Humphrey et al., 1994; Milner & Heywood, 1989; Milner et al., 1991). Colour specifically improved recognition of natural objects for both D.F. and control participants. From the studies mentioned above, it can be concluded that appropriate colour facilitates the recognition of the objects high in colour diagnosticity, whereas these objects are recognized more slowly and less accurately when inappropriately coloured.

Results found in object recognition studies can be extended to recognition of more complex stimuli, like scenes (Oliva & Schyns, 1997; Steeves et al., 2004).

A scene is usually defined as a semantically coherent, nameable view of an environment, composed of multiple discrete objects. In natural scenes (e.g., canyon, seashore, forest, desert), there is a more consistent colour pattern that serves as a recognition cue than there is in non-natural scenes (e.g., city, road, shop, room). Again, scenes high in colour diagnosticity (natural scenes) are more affected by colour manipulations than are scenes low in colour diagnosticity (non-natural scenes; Oliva & Schyns, 1997; Steeves et al., 2004). Moreover, Steeves et al. (2004) showed that the form agnostic patient D.F. used colour information to categorize scenes.

It is still under debate at which level in the visual pathway the beneficial effects of colour for recognizing natural scenes and objects occurs. Cases have been made for lower, sensory levels (e.g., Wurm, Legge, Isenberg, & Luebker, 1993) as well as for higher, cognitive processing stages (e.g., Humphrey et al., 1994). As mentioned above, Humphrey et al. (1994) concluded that colour facilitates naming of natural objects when presented in their diagnostic colour. Moreover, they concluded that this facilitation occurs at a high (-er) level of visual analysis, where knowledge of object properties, such as colour, is stored.

In contrast, Wurm et al. (1993) concluded that for recognizing objects, colour information plays a role at a sensory level. They investigated the role of colour in object recognition from the perspective that colour differences, like luminance differences, may provide reliable information for scene segmentation. For ecological reasons, they used images of food throughout their experiments. Their hypothesis was that colour may be particularly useful, when either the stimulus or the sensory processing is degraded, as in the case of low-pass filtered images, or low vision, respectively. In their first two experiments, they showed that colour speeds up object recognition about equally for normal and degraded vision (for both low-pass filtered images and low vision). To investigate the origin of the effect of colour, they carried out two more experiments. They presented participants with images of a same object from different perspectives—that is, the prototypical view and three views that deviated systematically from the

prototypical view. The results demonstrated that the effect of colour increases when images deviate more from the prototypical view. Wurm et al. (1993) suggested that nonprototypical views of objects are more difficult to recognize, and therefore benefit more from colour, because recognition is then “more dependent on surface characteristics”. Their final experiment was directly aimed at the question of whether explicit object-colour knowledge plays an additional role in the advantage of colour in object recognition. Wurm et al. (1993) used information theory to calculate the informational value of participants’ colour knowledge for a fixed set of food items, based on ratings from the same participants to what degree colour would be helpful for recognition. The algorithm showed that the recognition of, for example, a lemon or a carrot, would benefit more from colour information, than, for example, an apple or a pepper. Subsequently, Wurm et al. (1993) observed that this object characteristic, which they termed “colour diagnosticity”, did not correlate with the colour advantage found in the algorithm. They argued that explicit knowledge about food colour does not account for the advantage of colour in real-time object recognition. Their overall conclusion is that the primary role of colour in object recognition is sensory in nature.

In the present study we have the unique opportunity to further investigate the suggested low-level sensory colour processing versus the higher cognitive level of colour processing by examining the role of colour information in scene recognition in a patient with colour agnosia. Patients with colour agnosia have intact colour perception, as demonstrated by normal performance on, for instance, hue-matching tasks, but have no explicit colour knowledge (e.g., Nijboer, van Zandvoort, & de Haan, 2006). If scene recognition is improved by specific knowledge about which colours are appropriate for specific scenes, then we expect to find a reduced effect of colour on scene recognition in patients with colour agnosia. If instead, the colour diagnosticity effect is derived from low-level processes, agnostic patients should, similar to control participants, benefit from appropriate colour information. In other words, by using a scene recognition task with a colour

agnostic patient, we can distinguish between the above-mentioned higher and lower level explanations of the effect of colour in visual recognition.

CASE STUDY

M.A.H. is a 44-year-old male, who came to our attention after an infarct in the right cerebellar hemisphere, as confirmed with a magnetic resonance imaging (MRI) scan (see Figure 1). A more detailed description is presented in van Zandvoort, Nijboer, and de Haan (in press), and only a short summary is given here. Neuropsychological assessment in the acute phase showed, apart from residual dizziness, some mild deficits in memory functioning. At follow-up, two years later, his performance on all neuropsychological tasks tapping the major cognitive domains of reasoning, language, visual perception and construction, verbal memory, visual memory, executive functioning, and neglect was above average, taken into account his age and education (see Table 1, for neuropsychological data).

Surprisingly, he showed an absolute inability to perform the Token Test (de Renzi & Faglioni, 1978). He could not match the spoken colour name with coloured tokens, and on subsequent testing he was unable to name the primary colours presented to him on a monitor. Additionally, his ability to perceive colours was evaluated on three different tests. His performance on the Ishihara test for colour blindness (Ishihara, 1977) and the Farnsworth–Munsell 100 hue test (Farnsworth, 1957) was well in the normal range. In addition, an experimental task was used in which the threshold of the just-noticeable difference was established for three primary visual sensory cues (shape, colour, luminance, apparent motion; de Haan, Heywood, Young, Edelstyn, & Newcombe, 1995). M.A.H. was shown three simultaneously presented stimuli. Two stimuli in each test were identical, and the third differed in shape, colour, luminance, or apparent motion. Task difficulty changed in a 3-down, 1-up manner. M.A.H. encountered no problems in any of these tasks: He outperformed the control participants on the luminance test,

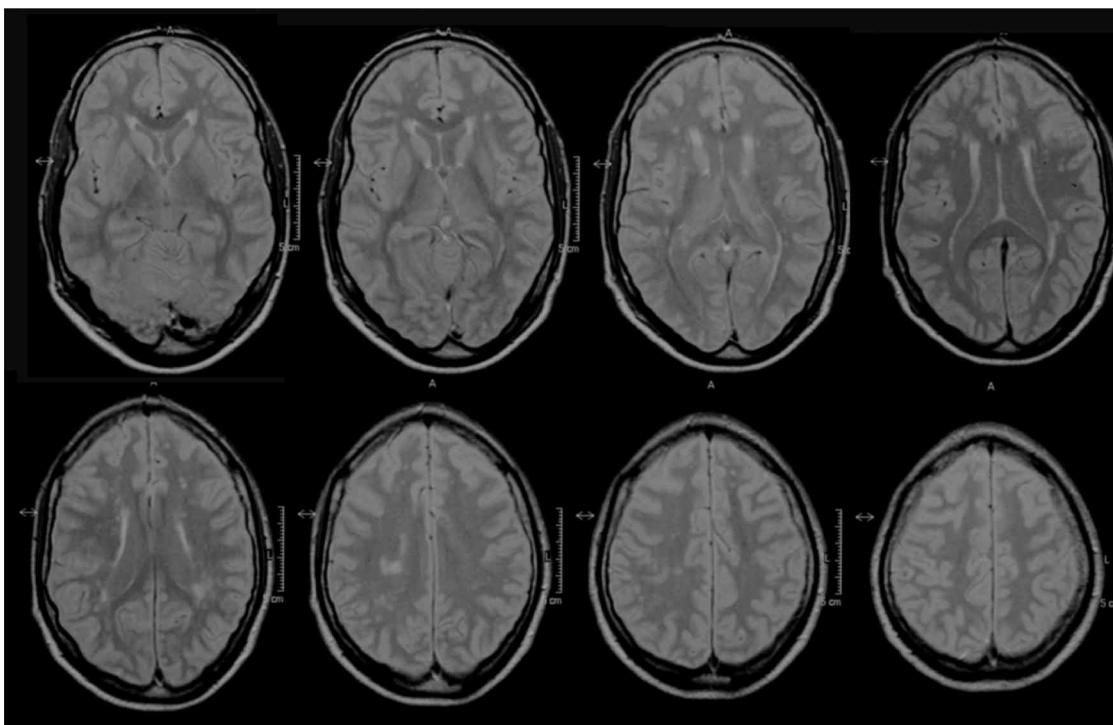


Figure 1. MRI (T2SE) for M.A.H. showing no brain abnormalities in the occipito-temporal cortices.

and he was within normal range on the shape, colour, and apparent motion tests (see Table 1).

Despite good colour perception, M.A.H. turned out to be impaired in categorizing and naming colour on the basis of hue. He performs at chance level on a task where he has to decide whether an object is depicted in the veridical colour or not (e.g., blue tomato). He claims that he has always had this problem. In daily life, he uses strategies to infer the colour of objects—for example, comparing the surface properties of an object with that of an object with a known colour (e.g., his shirt or grass), or he uses brightness cues (he is very proficient in judging brightness), and light colours are often identified as yellow or pink and dark ones as red or blue.

Influence of luminance and colour inversions in scene recognition

Our experiments were based on the experimental design of Steeves et al. (2004). The most important

conditions in their experiment for examining colour diagnosticity were normally coloured and inversely coloured images. Intrinsic to this colour manipulation is the fact that luminance information is inverted as well. This luminance inversion might complicate the recognition of scenes and might thus partly explain the poorer recognition of inversely coloured images. Since colour agnostic patients are perfectly able to use luminance information, it was essential to rule out this explanation beforehand. Therefore we tested 16 control participants on the scene recognition task to which a new format was added—namely, inverted greyscale.

Method

Participants

A total of 16 control participants (12 student controls and 4 age-matched controls; mean age = 29.9 years; $SD = 8.1$) and M.A.H. (44 years)

Table 1. Neuropsychological performance of M.A.H. at 27 months poststroke

Neuropsychological task	Poststroke score
<i>Reasoning</i>	
Raven APM	12/12 ^a
WAIS vocabulary	49/60 ^a
<i>Language</i>	
Boston Naming Task	180/180 ^a
Token Task	0/21 ^a
Letter Fluency	
UNCA	60
Category	39
<i>Memory</i>	
RAVLT	
Immediate rec.	59/75 ^a
Delayed rec.	14/15 ^a
Recognition	29/30 ^a
Doors Task	21/24 ^a
Rey-O figure delayed rec.	35/36 ^a
WAIS: digit span	19
Location Learning Task	
Displacement	14
Learning Index	0.50
Delayed Recall	0
Wechsler Memory Scale: paired associated	19/21 ^a
Corsi Block Span	6
<i>Executive functioning</i>	
Trailmaking	
A	33
B	52
<i>Visuoperception & -construction</i>	
Judgement of line orientation	28/30 ^a
Face Recognition Task	45
Rey-O figure copy	36/36 ^a
Ishihara test for colour blindness	25/25 ^a
Odd-one-out ^b	
Shape	1.27 ^c
Luminance	0.46 ^d
Colour	2.16
Motion	2.89 ^e
Farnsworth_Munsell 100 hue	44 errors ^f

Note: WAIS: Wechsler Adult Intelligence Scale; RAVLT: Rey Auditory Verbal Learning Task; Rey-O: Rey-Osterrieth Complex Figure.

^aThe first number is M.A.H.'s score on the test; the second number is the maximum score. ^bData of control participants on the odd-one-out paradigm: shape, 1.03 mm (*SD*: 0.68); luminance, 1.10 cd/m² (*SD*: 0.30); colour: 1.28 (*SD*: 0.78); motion: 2.33% coherent motion (*SD*: 1.63). ^cIn mm. ^dIn cd/m². ^ePercentage of coherent motion. ^fNormal range: 30–100 errors.

participated in the experiment. All participants had normal or corrected-to-normal vision and reported that they were not colour blind, which was confirmed with the Ishihara test for colour vision (Ishihara, 1977).

Apparatus and stimuli

Images were generated by a PC and were presented on a laCie Electron 22-inch blue IV display. Screen resolution was 1,024 × 768 pixels, and the computer was running in 256-colour mode. The viewing distance was 80 cm.

The stimuli were adapted from Steeves et al. (2004), and the greyscale images were manipulated in order to produce the inverted greyscale images. Images were first screened for category membership by 25 students, who did not participate in the scene recognition experiment, and only images that were correctly categorized by all students, in all formats, were included. The size of the images was 256 × 256 pixels, subtending approximately 8.2° × 8.2° of visual angle. There were three categories of natural scenes (coast, forest, and desert) and three categories of non-natural scenes (room, city, and market). Six different formats were used: normally coloured, inverted colour (each colour was replaced by the opponent colour in colour space, e.g., blue replaced by yellow, green replaced by red), greyscale, inverted greyscale, black-and-white (texture degraded), and spatially rotated images (by 180° along the horizontal axes, or upside down; see Figure 2 for examples of both a natural and a non-natural scene, used in the experiment, shown in all used formats). Black-and-white images and spatially rotated images were included for full comparison to the findings of Steeves et al. (2004). Here the focus was on the normally coloured images, and these were compared to all other control formats: inverted colour, greyscale, inverted greyscale, black-and-white, and spatially rotated images.

Procedure and design

The participants were tested individually in a quiet, darkened room. A trial started with a fixation dot for 500 ms, followed by a blank screen for 150 ms, which in turn was followed by an



Figure 2. Examples of the stimuli used in the scene recognition experiment (left panel: natural scene; right panel: non-natural scene).

image. Each trial was ended via a voice-key switch when the participant gave a verbal response. After a 150-ms pause, the next trial started. Before the experiment started, participants were given the category names of the different scenes along with an example image. They were instructed to name the category to which the image belonged, as quickly and accurately as possible. Verbal responses were recorded with a tape-recorder. No feedback was given during the experiment.

There were two within-subject manipulations: scene type (natural and non-natural) and format (normally colour, inverted colour, greyscale, inverted greyscale, black-and-white, and spatially rotated). Each participant was presented with 360 images (10 images per subsceen, all in the six different formats: 10 images \times 6 subsceens \times 6 formats).

Data analysis

The participants' responses and reaction times were recorded. All reaction times associated with incorrect responses (less than 2% per participant) were excluded from further analyses. From the overall reaction times for correct responses, trials with reaction times less than 150 ms were excluded, under the assumption that they were anticipatory responses, and reaction times over 2,500 ms were excluded, as they were interpreted as failures of the voice-key measurements. Any reaction times that were more than 2 standard deviations from the participant's mean were also excluded, as they

were interpreted as outliers. Fewer than 1% of the responses in total were excluded.

The reaction time data of the control participants were subjected to a two-way repeated measures analysis of variance. When Mauchly's Test of Sphericity was violated, the Greenhouse-Geisser correction was applied. For planned comparisons, paired samples t tests with Bonferroni correction for multiple comparisons were used for comparing normally coloured images to all other control formats (inverted colour, greyscale, inverted greyscale, black-and-white, spatially rotated).

Results and discussion

Figure 3 shows the mean reaction times of the control participants. We collapsed the data of the two control groups, resulting in one control group that is very comparable to the one used by Steeves et al. (2004). Moreover, it simplified the methodology to one experiment with one reliable control group. There was no difference in patterns of performance between the two groups of control participants (students and age-matched controls).

As can be seen in Figure 3, there was a significant main effect of scene type, with shorter overall reaction times for the non-natural scenes than for the natural scenes, $F(1, 15) = 6.808$, $p < .020$, which is in line with the data of Steeves et al. (2004). Moreover, there was a significant main effect of format, with the format of the scene

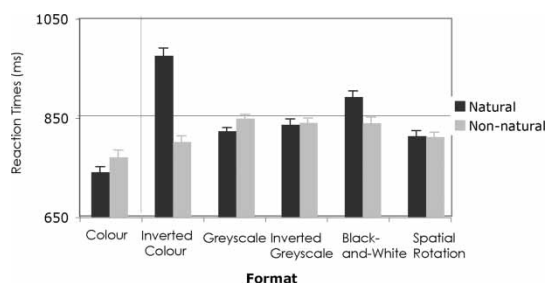


Figure 3. Mean verbal reaction times (ms) and standard errors of mean (derived from the within-subjects mean square error term) of the control participants for natural and non-natural scenes in six different formats.

image affecting reaction times across scene types, $F(5, 75) = 29.827$, $p < .001$. Furthermore, there was a significant interaction between scene type and format, $F(5, 75) = 24.584$, $p < .001$: Colour inversion had a large effect on the reaction times of natural scenes, whereas it did not influence non-natural scenes. Reaction times were much longer on the colour inverted images than on normally coloured images for the natural scenes, $t(15) = -10.545$, $p < .001$, whereas reaction times on the colour inverted images did not differ from the normally coloured images for the non-natural scenes, $t(15) = -1.795$, $p > .05$. Appropriate colour facilitated recognition of natural scenes, as reaction times were shorter for normally coloured images than for all other control formats: black-and-white, $t(15) = -9.2164$, $p < .001$; greyscale, $t(15) = -5.293$, $p < .001$; inverted greyscale images, $t(15) = -8.790$, $p < .001$; and spatially rotated images, $t(15) = -7.658$, $p < .001$. For non-natural scenes, reaction times were shorter for normally coloured images only when compared to black-and-white, $t(15) = -5.222$, $p < .001$; greyscale, $t(15) = -6.241$, $p < .001$; and inverted greyscale images, $t(15) = -5.196$, $p < .010$. This effect is also in accordance with Steeves et al. (2004). Importantly, for both natural and non-natural scenes, there was no difference in reaction times between greyscale and inverted greyscale images.

In short, colour manipulations had a large influence on scene recognition for natural images but

not for non-natural images. This is in line with the colour diagnosticity hypothesis. Luminance inversion does not play a role in scene recognition.

Scene recognition in colour agnosia

Having established that it is appropriate colour, not appropriate luminance, that is crucial for rapid scene recognition, we examined M.A.H., a man with developmental colour agnosia. Less than 1% of the data of M.A.H. was excluded due to incorrect responses.

The mean reaction times in the six formats per scene of M.A.H. are presented in Figure 4. As can be seen, there was a significant main effect of scene type, with overall shorter reaction times for the non-natural scenes than for the natural scenes, $F(1, 299) = 18.72$, $p < .001$. There was no significant main effect of format, indicating that the format of the scene image did not affect reaction times irrespective of scene type. In addition, there was no significant interaction.

In order to directly compare the pattern of performance of a single case (M.A.H.) on the normally coloured images versus the other control formats with that of the control participants, we used Crawford, Howell, and Garthwaite's (1998) modified paired samples t test. With this test, we compared the magnitude of the differences between reaction times for colour images and the other formats for M.A.H. with the magnitude of differences between reaction times for colour images and all other formats for the control participants. The planned comparisons using Crawford et al.'s statistics were done with a Bonferroni correction for multiple comparisons.

Overall, M.A.H.'s mean reaction times were longer than those of the control group, for both the non-natural, $t(15) = 3.395$, $p < .010$, and the natural scenes, $t(15) = 7.251$, $p < .001$.

In spite of his longer reaction times, M.A.H.'s pattern of performance on the non-natural scenes resembled the pattern of performance observed in student and age-matched control participants (see also Figure 3); the magnitude of the differences between normally coloured and all other control formats of M.A.H. fell within the

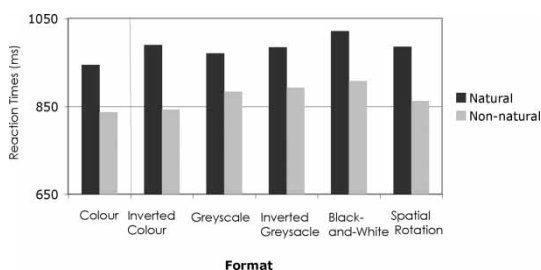


Figure 4. Mean verbal reaction times (ms) of M.A.H. for natural and non-natural scenes in six different formats.

normal range of the control participants (for all comparisons between normally coloured and the other formats used, $p > .050$). In other words, the effect of colour manipulations on the recognition of non-natural scenes is not statistically different between M.A.H. and controls.

M.A.H.'s pattern of performance on the natural scenes, however, differed from that of the control participants. As is apparent from Figure 3, the reaction times of control participants to the natural scenes presented in inverted colour were much longer than those of normally coloured images. For M.A.H., there was no difference in reaction times for images presented in inverted colour than for normally coloured images. This lack of an effect of colour manipulations for M.A.H. is very different from the effect that colour manipulations have on reaction times for the control participants, $t(15) = 7.019$, $p < .001$. In addition the absence of a beneficial effect of colour over greyscale and inverted greyscale for M.A.H. was different from the effect of the control participants, $t(15) = 3.691$, $p < .050$, and $t(15) = 3.269$, $p < .050$, respectively. In other words, the absence of differences between colour and inverted colour, greyscale, inverted greyscale, black-and-white, and spatially rotated images of M.A.H. did not fall within the normal range of the control participants.

Note that the lack of an effect of colour for M.A.H. on the natural scenes condition is not merely an overall inability to name scenes fast and accurately irrespective of format—for example, a floor effect. This notion, tempting though it is,

cannot explain his normal performance on the non-natural scenes. This suggests that M.A.H. does not use colour information to assist him in scene recognition irrespective of colour diagnosticity.

GENERAL DISCUSSION

Colour is an important visual cue. It helps us to decide for instance whether fruit is ripe, and, in a more general sense, it helps us to recognize our environment. Several studies have demonstrated that especially natural scenes and objects are recognized better when presented in a colour that is deemed diagnostic for these scenes and objects. Other features, such as contour and visual texture, are especially informative for recognizing non-natural scenes and objects (see below).

The purpose of the present experiments was to examine the role of colour information for scene recognition in colour agnosia. First, we established that the deterioration in scene recognition because of colour inversion found in other studies could not be attributed to the luminance inversion intrinsic to this manipulation. Second, we investigated the level of visual analysis at which colour influences scene recognition by testing a colour agnostic patient. Colour manipulations did not influence the recognition of natural scenes for M.A.H. in the same way that it did for the control participants. Interestingly, M.A.H.'s performance on the natural scenes compared to non-natural scenes was degraded independent of the scene format, as normally coloured and colour-inverted, as well as achromatic, images were responded to with longer reaction times. This could not be attributed to additional processing deficits, such as form or texture (see also Table 1), or an overall inability to name scenes fast and appropriately, as his performance on the non-natural scenes was within the range of the control participants.

Which cues are informative for scene recognition?

Obviously, colour is but one of the features for recognizing objects and scenes. Computational

models that permit accurate scene classification without the prior recognition of individual objects (Oliva & Torralba, 2001; Vailaya, Jain, & Zhang, 1998) make use of properties such as the spatial complexity of the scene, visual texture, and colour (Oliva & Schyns, 2000; Oliva & Torralba, 2001). Natural scenes are composed of undulating contours and complex textures, but have characteristic colours. For non-natural scenes, texture and contour cues are more informative, whereas colour cues are not so straightforward. In other words, colour is the key property for recognizing natural scenes, whereas shape and texture are the key properties for recognizing non-natural scenes (Tanaka & Presnell, 1999). Since colour can only become diagnostic when one learns that certain objects or scenes tend to have certain colours, M.A.H., who has developmental colour agnosia, never learned this diagnostic value and thus lacks the benefit of colour information for recognizing natural scenes. His poorer internal representation of colour (e.g., impaired colour imagery, conceptualization, and explicit associations; Nijboer et al., 2006; van Zandvoort et al., in press), due to his developmental colour agnosia together with only texture and contour cues available for recognizing the scenes, resulted in his overall slower, but still very accurate, recognition of natural scenes. In other words, it is the specific combination of an impaired association between natural scenes and specific colours and the spatial complexity (complex textures and contours) of these natural scenes that can explain his overall slowing in recognizing the images.

Based on M.A.H.'s performance on the scene recognition task, one would expect a patient with visual form agnosia to show the inverse pattern—that is, slower performance on the non-natural scenes. Interestingly, this is exactly what has been found in the study of Steeves et al. (2004; see their Figure 4), where D.F. was much slower in identifying non-natural scenes than natural scenes. These findings are in line with the results of Tanaka and Presnell (1999) who found that when shape information is degraded, recognition of objects low in colour diagnosticity

is more impaired than recognition of objects high in colour diagnosticity.

Levels of visual processing

An important reason for testing scene recognition in colour agnosia is that there still is considerable debate about the level of visual analysis at which colour influences recognition of objects and scenes. By testing a colour agnostic patient, we can distinguish between these levels of analysis. Colour associations and semantic representations are selectively impaired or lost, but low-level colour perception is not affected in colour agnosia (van Zandvoort, Nijboer, & de Haan, in press). Any deviation in performance on the scene recognition task is therefore more likely to be attributable to a deficit in processing of colour information at a higher cognitive level than to a deficit at a sensory level. Wurm et al.'s (1993) conclusion of a sensory role for colour was based upon results from experiments in which all objects would, according to the definition used in our as well as Price and Humphrey's (1989) experiments, make up a colour diagnostic stimulus set. Apparently, the level of diagnosticity (high or low, e.g., carrot or apple, respectively) does not influence the beneficial effect of presenting objects in their diagnostic colour. Note, however, that our conclusion about M.A.H.'s performance does not depend upon either the definition of colour diagnosticity or the stimulus set used (see Introduction).

Therefore we can conclude, in line with Price and Humphreys (1989), that the *characteristic* colour of an object or scene is stored in the structural or semantic representation of that object or scene. Apparently, the surface property colour linked to specific (i.e., natural) objects or scenes is stored in memory. The beneficial effect of appropriate colour in recognizing natural scenes occurs at a higher cognitive level and is the result of internal colour representations, based on learned associations.

Manuscript received 16 February 2006

Revised manuscript received 3 August 2006

Revised manuscript accepted 31 August 2006

First published online 5 December 2006

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