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Letter to the Editor

Glossiness perception can be mediated independently of cortical processing of colour or texture

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Visual recognition of objects relies not only on their shape but also on the properties of materials of which they are made (Adelson, 2001). Perception of two of these properties, colour and texture, depend upon nearby, but anatomically distinct, areas of cerebral cortex (Cavina-Pratesi et al., 2010a, 2010b). A third property, glossiness, is conceptually distinct from texture and colour. In order to determine whether glossiness is processed in the same region of cortex as these other material properties we tested the glossiness perception of a neurological patient who, we have reported elsewhere, is unable to discriminate colours or textures and lacks the cortical areas responsible for mediating their perception.

Cant and Goodale (2007) first showed that attending to the material properties of objects or to their shape activate distinct regions of cortex. We extended this work by showing that texture and colour activate different regions (Cavina-Pratesi et al., 2010a, 2010b). Regions responding exclusively to texture or colour are distinct (posterior collateral sulcus *vs* anterior collateral sulcus and lingual gyrus) but lie in close proximity, sharing a common region which is activated by both colour and texture. This might suggest that different material properties are processed by a constellation of nearby regions of cortex. The psychophysics of colour and texture perception suggests that both have complex computational underpinnings (Foster, 2011; Emrith et al., 2010). Percepts of objects' glossiness are influenced by quite different properties of an image. The skew of the reflected lightness distributions of objects influences glossiness perception in simple tasks (Motoyoshi et al., 2007) although skew itself may not be computed by the visual system (Kim and Anderson, 2010). Indeed, when comparisons of glossiness must be made between different objects, glossiness depends upon the relationship between lightness and shape (Anderson and Kim, 2009) and, especially when the lighting of a scene changes, can be computationally complex (Olkkonen and Brainard, 2010). Is glossiness nevertheless processed in an area close to those involved with other surface properties or is it processed elsewhere in the cortex?

In our studies of material perception we tested a neurological patient, MS, along with normal observers. MS suffered extensive brain damage in 1970 and has a left hemianopia, complete achromatopsia, prosopagnosia, visual object agnosia together with a variety of memory deficits (see e.g., Heywood and Kentridge, 2003; Kentridge et al., 2004). His Snellen acuity is, however, normal in both eyes (Mollon et al., 1980). MS performs at chance on tests of texture and colour discrimination. Neuroimaging revealed that he was lacking the regions activated in response to texture and colour in normal observers. If MS can discriminate glossiness it would imply that it is processed in a location distinct from the regions involved in texture and colour perception.

To determine what MS understands by 'glossiness' we read him a list of 54 everyday glossy and non-glossy items, asking him to give a very brief description of each. In a test of imagery, we randomly paired 18 glossy and 18 non-glossy items that MS had earlier described correctly and asked him which of each pair was the glossiest (e.g., "Which is glossier, cutlery or carpet?"). MS performed well, answering 15 out of 18 questions correctly and clearly understanding the questions. His success at this task is in contrast with his difficulty in tackling tests of colour imagery.

In our first test of glossiness perception we presented MS with sets of three real objects (table-tennis balls sprayed with specially mixed paints) where two had the same glossiness and one had a different glossiness (Fig. 1). The odd item was always at the top or bottom of the triplet, so chance performance was 50% (we have consistently found that MS tackles this top/bottom 3-item oddity task more easily than a 3-choice task). We

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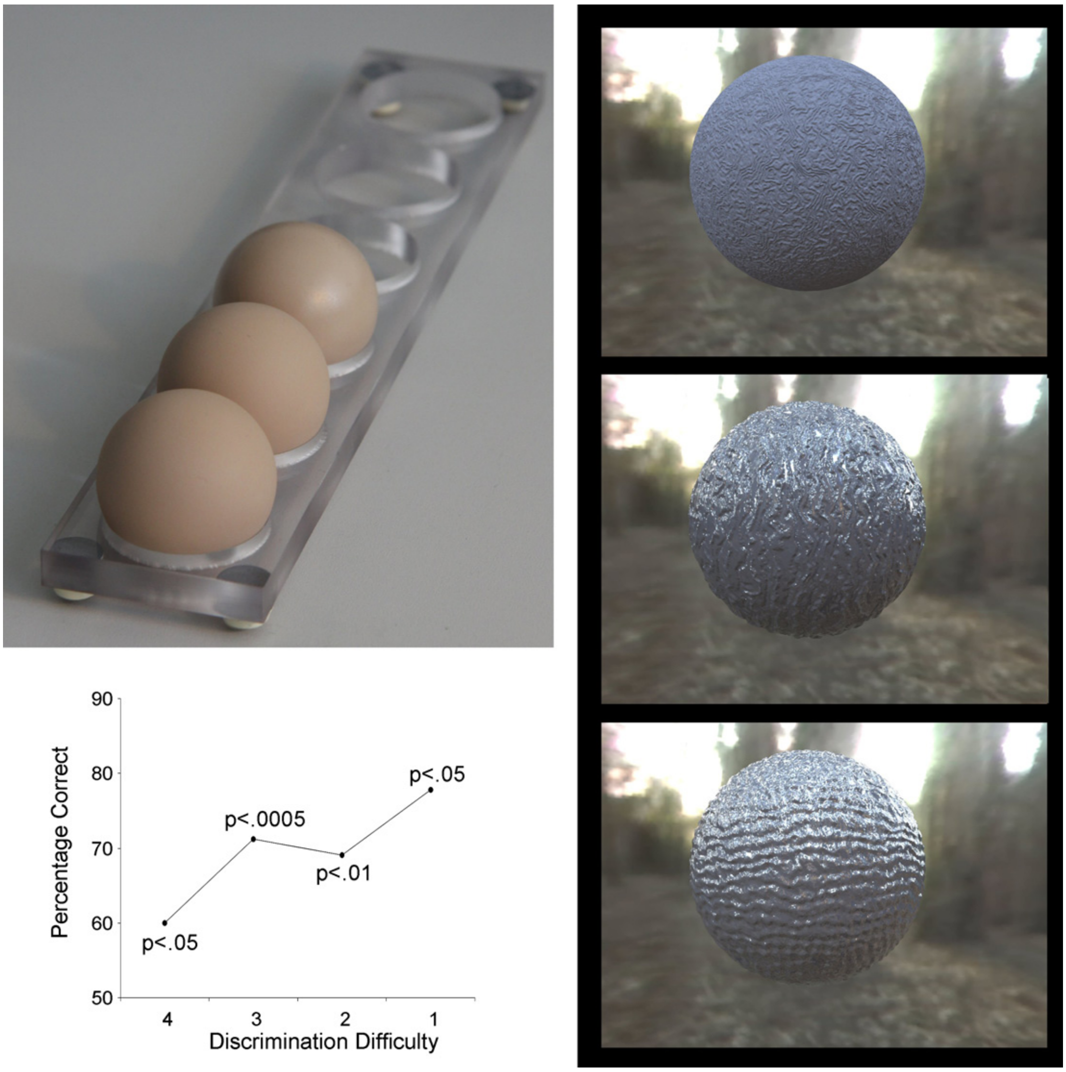

Fig. 1 – Stimuli and results. The upper left-hand panel shows three of the physical stimuli, table-tennis balls painted with mixtures of gloss and silk paints in their holder. The uppermost sphere is painted with a glossier paint-mixture than the other two spheres. The right-hand panel shows three of the computer generated stimuli used in experiment 2. The lower pair of spheres has the same glossiness; the upper sphere is less glossy. All three spheres have different reflectances and different surface textures. The spheres are modelled using a custom C++ program, rendered using the physics-based raytracing package RADIANCE (Ward and Shakespeare, 1998) and illuminated with a natural lighting distribution (Debevec, 1998). Part of the scene providing that lighting distribution can be seen in the backgrounds of the images. The lower left-hand panel shows oddity performance of MS for the four levels of glossiness difference in these images together with the associated binomial probabilities.

used a variety of glossinesses to produce 40 test combinations. MS indicated the odd item correctly on 26 of 40 trials (65%). This performance is significantly better than chance (binomial probability $p < .05$). The task is, however, difficult. Eighteen young control participants failed to produce errorless performance (on average they succeeded on 91% of trials).

In this initial test MS performs better than chance, but not by a great margin. We could not achieve large differences in glossiness with real objects and untextured spheres do not provide rich cues to glossiness. Moreover, the task could, in principle, be solved by attending to oddity in a single feature of the stimuli (e.g., the specular highlight on each ball) or to their average luminances. In our second experiment we controlled for these two potential artefacts. The stimuli were trios of computer generated images of spheres rendered under a natural lighting distribution and presented on a computer monitor (Fig. 1). All three spheres on any trial had different overall reflectances and different textures from one another but two of the spheres matched in glossinesses while one had a different glossiness. We were able to vary the glossiness of items over a much wider range and so could analyse the effect of discrimination difficulty by grouping trials according to the difference in the glossiness between the odd item and foils.

Discriminations were divided into four difficulty levels with 90, 66, 42 and 18 trials in each from hardest to easiest (the numbers of trials differ because we presented equal numbers of trials of every glossiness combination so there are relatively few extreme, and hence easy, differences available). Overall MS made 144/216 (61%) correct discriminations. There is less than one chance in a million (binomial test) that his performance was due to chance. MS performed better than chance at every level of difficulty with a rising trend in performance as the glossiness difference increased [with scores and binomial probabilities of 54/90 (60%), $p = .036$; 47/66 (71%), $p = .00038$; 29/42 (69%), $p = .0098$ and 14/18 (78%), $p = .015$ for the four descending degrees of difficulty]. Normal observers show the same rising trend in performance across difficulty levels (averages of 81%, 93%, 99% and 100% from nine young control participants).

The randomisation of lightness and texture meant that the oddity task could not be solved on the basis local feature comparisons (the location and size of specular highlights varies according to an object's texture) or other simple image statistics such as lightness distribution means, ranges, variances or skewnesses. We computed these statistics for each object and tested whether differences between the odd item and foils in each triplet of objects for each statistic varied systematically across task difficulty levels. We found no such differences and present statistical analyses in the supplemental materials.

The clear abilities that MS demonstrated in glossiness perception, in conjunction with the fact that he has lost cortical areas necessary for perception of texture and colour mean that we must conclude that glossiness does not depend exclusively upon processing in the same constellation of regions that are necessary for the perception of colour or texture. MS does perform more poorly than young controls but this difference may well be a consequence of his other deficits, in particular his hemianopia which means he cannot use central vision to see the stimuli in their entirety. Alternatively, glossiness may be processed in more than one cortical area (as the different demands of glossiness constancy and simple glossiness judgements might suggest) and the relatively poor performance of MS may be due to loss of some, but certainly not all, of these areas.

Supplementary material

Supplementary material related to this article can be found online at doi:10.1016/j.cortex.2012.01.011.

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