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Look but don't touch: Visual cues to surface structure drive somatosensory cortex

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ABSTRACT

When planning interactions with nearby objects, our brain uses visual information to estimate shape, material composition, and surface structure *before* we come into contact with them. Here we analyse brain activations elicited by different types of visual appearance, measuring fMRI responses to objects that are glossy, matte, rough, or textured. In addition to activation in visual areas, we found that fMRI responses are evoked in the secondary somatosensory area (S2) when looking at glossy and rough surfaces. This activity could be reliably discriminated on the basis of tactile-related visual properties (gloss, rough, and matte), but importantly, other visual properties (i.e., coloured texture) did not substantially change fMRI activity. The activity could not be solely due to tactile imagination, as asking explicitly to imagine such surface properties did not lead to the same results. These findings suggest that visual cues to an object's surface properties evoke activity in neural circuits associated with tactile stimulation. This activation may reflect the a-priori probability of the physics of the interaction (i.e., the expectation of upcoming friction) that can be used to plan finger placement and grasp force.

Introduction

When we look at objects, we are able to predict how they will feel once we come into contact with them. For instance, shiny objects with *glossy* surfaces, like silverware and plastic, are expected to feel smooth and hard when pressed, and sliding our fingers over their surface may generate stick–slip interactions. Textured objects, like a tree bark and sandpaper, are expected to feel rough when pressed upon and can lead to abrasion if stroked. Matte objects, like wood and stone, are expected to feel irregular and can generate skin vibration if caressed. These expectations refine movement planning, e.g., slippery objects necessitate a more precise and powerful grip.

While these issues have been appreciated at the conceptual and theoretical levels (Fleming, 2014; Xiao et al., 2013), work examining the neural underpinnings of visual appearance has mainly concentrated on responses from classically defined visual responsive cortical areas. Human brain imaging work and electrophysiological recordings have suggested the importance of ventral cortical areas in processing information about surface textures and material categories (Cant et al., 2009; Cant and Goodale, 2007; Cavina-Pratesi et al., 2010a, 2010b; Goda et al., 2014; Hiramatsu et al., 2011). However, given the potential importance of visual cues in driving the nature of our interactions with nearby objects, the role of somatosensory areas during visual surface perception is still unclear. Previous studies have shown that the somatosensory cortex is important for tactile perception of texture and roughness (Kaas et al., 2013; Kitada et al., 2005; Pruett et al., 2000; Roland et al., 1998; Sathian et al., 2011; Simões-Franklin et al., 2011; Stilla and Sathian, 2008). Here we ask whether this region responds also to visually presented information about similar surface properties.

Several groups have identified areas in human visual cortex whose activity relates to tactile and haptic stimuli. In one human fMRI study, object-sensitive regions in occipitotemporal cortex (including the lateral occipital region (LO) and posterior fusiform sulcus (pFs)) were identified to represent information about object weight when lifting visually presented objects. Moreover, after learning that object textures were associated to object weight, this texture–weight association was also represented in occipitotemporal areas (Gallivan et al., 2014). A second fMRI study has similarly shown haptic object-selective activity in occipitotemporal cortex (Amedi et al., 2001). Further studies have found haptic texture-selective responses in the middle occipital cortex and haptic shape- and location-selective responses in intraparietal sulcus (IPS) (Sathian et al., 2011; Stilla and Sathian, 2008). These results suggest that occipitotemporal areas, middle occipital cortex, and IPS are actually not strictly visual, but bimodal as they are capable of representing haptic information as well. Thus, it is possible that crossmodal activations may exist for other primary sensory areas, i.e.

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visual texture-selective responses may also be found in somatosensory cortex.

To test whether somatosensory areas respond to visually defined textures, we measured human fMRI responses to visual images of computer-generated objects that had perceptually different surface characteristics. The stimuli were designed to evoke a visual impression of surface gloss or roughness, while the control conditions were designed to depict stimuli with similar image statistics that nevertheless gave rise to a different impression of surface properties. All the stimuli were novel objects to avoid issues of remembered sensations. We used multivoxel pattern analysis (MVPA) to test for visual and somatosensory areas that contained neuronal responses that supported reliable discrimination of different visual surface characteristics. Our rationale was that if the brain has a system to generate expectations of tactile sensations when looking at objects with distinctive surface properties, changes in appearances that affect such expectations should elicit different activation responses in somatosensory cortex. Indeed, we found this to be the case. In a control experiment, we further show that imagining such surface properties is alone insufficient to generate similar somatosensory activations.

Materials and methods

Participants

Sixteen participants who had normal or adjusted-to-normal vision were recruited for the experiments. One was the author H.-C. S. and the remaining participants were naive to the tasks and purpose of the study. All were screened for visual acuity and MRI safety before being invited to participate. The age range was 18–39 years old, and 5 of the 16 participants were male. All participants gave written informed consent before taking part in the experiment. The study was conducted according to the protocol approved by the STEM Ethical Review Committee of the University of Birmingham. After completing the experiment, all participants (except the author) received monetary compensation or credits.

Apparatus and stimuli

Stimuli

The study comprised three 3-D shaped objects generated by Blender 2.67a selected from a previous study (Sun et al., 2015) (Fig. 1A). Stimuli were 12 deg. in diameter on average, and they were presented on a midgray background. We created versions of the stimuli for each object that made up the four conditions of the experiment: Glossy, Glossy Control, Rough, and Rough Control (Fig. 1B). In the Glossy condition, objects were rendered using a mixed shader with 90% diffuse and 10% glossy components. In Glossy Control condition, the specular components rendered on Glossy objects were rotated by 45 degs in the image plane, which made the objects look matte since the important contextual information for gloss perception had been destroyed (Anderson and Kim, 2009; Kim et al., 2011; Marlow et al., 2011). In the Rough condition, wave textures were applied to objects' 3-D geometry, resulting in bumps on the surface. In the Rough Control condition, the same wave textures were applied to the objects' surface colour, resulting in a painted texture. In Glossy and Glossy Control conditions, there were five levels of the emission strength from the light source: 1, 1.2, 1.4, 1.6, and 1.8 (Fig. 1C). In Rough and Rough Control conditions, there were five levels of wave texture scale: 12, 17, 22, 27, and 32 (Fig. 1D). The five levels of each object were presented in a random order to reduce adaptation of the fMRI response. A black fixation dot (dia = 0.5 deg) was shown during fixation blocks.

In the control experiment, 12 new objects were presented to participants in familiarisation session before entering the scanner. The 12 objects were split in 4 groups that were rendered with a clear colour–condition association (i.e. blue objects were Gloss, red objects were Rough Control, etc). Then, participants were presented with only the contours of the previously seen objects that were filled with homogeneous colour. Participants were asked to imagine the surface properties of the four conditions specified by the colour. The colour-coding of Glossy/Glossy Control and Rough/Rough Control was counterbalanced across participants. Participants were trained to associate the colour cues with the four conditions and were able to make colour–condition associations with 100% accuracy prior to entering the scanner (and upon re-test after the scan). During the scan, there were five levels of luminance scale for each object contour presented in a random order to reduce any adaption effect in the fMRI response, as in the main experiment.

Apparatus

The same apparatus were used as described in our previous paper (Sun et al., 2015). Psychtoolbox (Brainard, 1997) was used for stimulus presentation. A JVC DILA SX21 projector was used for projecting stimuli on a translucent screen inside the bore of the magnet. Participants viewed stimuli via a mirror fixed on the head coil with a viewing distance of 64 cm. Luminance outputs were linearised and equated for the RGB channels separately with colorimeter measurements. A five-button optic fibre button box was used to collect participants' responses in the 1-back task.

MRI data acquisition

A 3-Tesla Philips scanner and an 8-channel phase-array head coil were used to obtain all MRI images at the Birmingham University Imaging Center (BUIC). T1-weighted high-resolution anatomical scans (175 slices, TR 8.4 ms, TE 3.8 ms, flip angle 8 deg., voxel size: 1 mm^3) were obtained for each participant. Functional whole brain scans with echo-planar imaging (EPI) sequence (32 slices, TR 2000 ms, TE 35 ms, voxel size $2.5 \times 2.5 \times 3$ mm, flip angle 80 deg., matrix size 96×94) were also obtained for each participant. The EPI images were acquired in an ascending interleaved order for all participants.

Design and procedure

Subjective rating task

Seven naive participants were recruited for the rating experiment. Participants performed glossiness ratings on all Glossy and Glossy Control stimuli in one block and roughness rating on all the Rough and Rough Control stimuli in another block. The order of the two blocks was balanced across participants. Participants viewed stimuli presented on a CRT monitor with a viewing distance of 83 cm. Luminance outputs were linearised and equated for the RGB channels separately with colorimeter measurements. The diameter of the stimuli was 12 deg. Each image was presented for 500 ms after which participants were given unlimited time to rate the image along a scale of “very glossy” to “very matte” for glossiness rating block, or along a scale of “very rough” to “very smooth” in the roughness rating block. Participants were permitted to place their rating bar in any position between the two ends to indicate their rating and the rating value was calculated by computing the distance between the bar and one end divided by the whole scale length.

fMRI session

A block design was used. Each participant took part in 9 or 10 runs with 368 s length of each run in a 1.5-h session. Each run started with four dummy scans to prevent start-up magnetisation transients and consisted of 16 experimental blocks each lasting 16 s. There were 4 block types (i.e., one for each condition), repeated four times in a run. During each block, fifteen objects were presented once in a pseudo-random order and one of them was shown twice (the “event” to which participants had to respond). Stimuli were presented for 500 ms with 500 ms interstimulus interval (ISI). Participants