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A comparison of haptic material perception in blind and sighted individuals

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A B S T R A C T

We investigated material perception in blind participants to explore the influence of visual experience on material representations and the relationship between visual and haptic material perception. In a previous study with sighted participants, we had found participants' visual and haptic judgments of material properties to be very similar (Baumgartner, Wiebel, & Gegenfurtner, 2013). In a categorization task, however, visual exploration had led to higher categorization accuracy than haptic exploration. Here, we asked congenitally blind participants to explore different materials haptically and rate several material properties in order to assess the role of the visual sense for the emergence of haptic material perception. Principal components analyses combined with a procrustes superimposition showed that the material representations of blind and blindfolded sighted participants were highly similar. We also measured haptic categorization performance, which was equal for the two groups. We conclude that haptic material representations can emerge independently of visual experience, and that there are no advantages for either group of observers in haptic categorization.

1. Introduction

In recent years, the interest in investigating the perception of object surface properties, such as material classes and material properties, has been growing. One goal has been to examine how different material surface properties or more generally textures are perceptually organized and represented in different modalities (Baumgartner, Wiebel, & Gegenfurtner, 2013; Bergmann Tiest & Kappers, 2007; Bhushan, Rao, & Lohse, 1997; Fleming, Wiebel, & Gegenfurtner, 2013; Hollins et al., 2000, 1993; Okamoto, Nagano, & Yamada, 2013; Picard et al., 2003; Rao & Lohse, 1996). In a previous study, we found the visual and haptic material representations of sighted participants to be highly congruent (Baumgartner, Wiebel, & Gegenfurtner, 2013). However, material categorization performance was better with visual material exploration than with haptic exploration. Even though the two senses are separate systems in material perception, they seem to be tightly coupled. In the present study, we want to investigate the coupling between vision and haptics further by comparing congenitally blind participants who lack any visual experience to blindfolded sighted participants.

Two questions concerning material perception in blind participants are treated here: Do the mental representations of materials differ between sighted and blind participants, and are there differences in material categorization performance between the two groups? On the one hand, one might expect an altered representation in blind participants because they lack visual guidance in haptic experience and visual imagery. On the other hand, blind observers have more extensive training on haptic stimuli. This might provide them with benefits when categorizing materials and might lead to a different perceptual organization of material properties.

So far little research has been conducted on how blind participants tactually perceive natural materials. In contrast to individuals with intact vision, blind people presumably rely more on the tactile sense to orient themselves in the world, for example to read or to navigate. The general idea of compensation between the senses has been proposed by Diderot in the 18th century (Diderot, 1770/1916). Indeed, blind Braille readers have been shown to possess enhanced spatial acuity in a grating orientation task (Goldreich & Kanics, 2003; Stevens, Foulke, & Patterson, 1996; Van Boven et al., 2000; but see Grant, Thiagarajah, & Sathian, 2000). However, other authors have found no tactile

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superiority in blind people (Grant, Thiagarajah, & Sathian, 2000; Heller, 1989a). These diverging results might be explained by acquired tactile experience (Van Boven et al., 2000; Wong, Gnanakumaran, & Goldreich, 2011). Specifically, extensive training through Braille reading may lead to an advantage in tactile acuity tasks.

Several studies have investigated the perception of shapes or pictures in the form of raised-line drawings in blind participants, especially since such tangible images and maps could be useful for blind individuals. The results here are mixed, with some studies reporting advantages for blind (D'Angiulli, Kennedy, & Heller, 1998; Heller, 1989b) and some reporting better performance of sighted participants (Bailes & Lambert, 1986; Heller et al., 2002; Lederman et al., 1990), or no difference (Picard et al., 2010). Factors such as experience with the type, size and nature of the displays, and task demands surely play a role in the inconsistency of the results. Another factor that has repeatedly been investigated and quite probably influences performance in such tasks is the time at which individuals have become blind. It has often been shown that late blind and blindfolded sighted participants outperform congenitally blind participants in tasks involving raised line drawings (e.g., Heller, 1989b; Heller et al., 1996). However, D'Angiulli, Kennedy, and Heller (1998) investigated blind and sighted children and found blind children to outperform the control group when they were allowed to explore the stimuli actively. Nevertheless, the often observed advantage of late blindness emphasizes the role of visual experience in tactile perception. According to Lederman et al. (1990), visual imagery could be crucial for object representation in the tactile domain. This has also been shown for shapes. In a study using bell peppers in a shape discrimination task, Norman and Bartholomew (2011) showed that congenitally blind participants performed worse than participants with acquired blindness, even though they showed a tendency of enhanced tactile acuity compared to both late blind and sighted participants.

But how much does visual experience and visual learning contribute to the perceptual representations of material properties and the categorization of material classes in the haptic modality? To our knowledge, the only study that has investigated some aspects of material perception in blind participants has been conducted by Heller (1989a). Heller used sandpaper in a roughness discrimination task and found no difference between congenitally blind, late blind and sighted participants. The question remains whether this pattern of results generalizes to a broader range of different tasks and material qualities. We wanted to investigate whether the perceptual interpretations of material properties in the haptic sense are represented similarly or differently in the two groups of observers. Since material categories are tightly linked to material property judgments (Fleming, Wiebel, & Gegenfurtner, 2013), we also tested whether there are performance differences in the categorization of materials.

First, we compared the semantic representation of material properties by means of a principal components analysis (PCA) in congenitally blind and sighted participants. Secondly, we compared the categorization performance of congenitally blind and sighted participants.

2. Materials and methods

2.1. Participants

Five blind participants (one female, four male) performed both tasks (see Table 1). All but one were right-handed. Four of them were congenitally blind, and one was born with severe visual deficits and turned fully blind at 6 months of age. They received financial compensation for their participation in the experiment. All participants gave informed consent prior to data collection. The work was carried out in accordance with the principles laid down in the Declaration of Helsinki.

Table 1
Blind participants.

Number	Sex	Age	Cause of blindness	Age of onset	Handedness
1	m	34	Retinal degeneration	Birth	r
2	m	19	Retinopathia praematurorum	Birth	l
3	m	24	Cancer	Birth	r
4	f	22	Glaucoma	Birth	r
5	m	32	Retinitis Pigmentosa	6 months	r

2.2. Data from sighted participants

The data for sighted participants was derived from Baumgartner, Wiebel, and Gegenfurtner (2013). Twelve sighted participants had taken part in this study, an additional five participants had provided the categorization data. Sighted participants had been blindfolded during haptic material exploration.

For the present study, the number of stimuli was reduced from 84 to 70 for the blind participants in order to reduce testing time. In addition, purely visual properties of the previous study were eliminated (i.e., glossiness, colorfulness, and texture). Otherwise, the present study was conducted as the previous one. For comparison with the blind participants, the eliminated material samples and properties were omitted in the analysis of sighted participants haptic data. We only used data from those six participants who had completed the haptic ratings before the visual ratings to exclude effects of visual experience with our stimulus set in sighted participants.

2.3. Stimuli

Our stimuli consisted of 70 material samples (14×14 cm in size) that were glued onto pieces of 12 mm thick medium density fiberboard (MDF). Stimuli comprised seven general material categories (10 stimuli/category): plastic, paper, fabric, fur and leather, stone, metal, and wood. Our stimuli can be seen in Fig. 1.

2.4. Material properties

We asked our participants to rate seven material properties accessible to the haptic sense on a 7-point Likert scale.

2.4.1. Roughness

How rough or smooth does the material appear to you? Low values indicate that the surface feels smooth; high values indicate that it feels rough.

2.4.2. Orderliness

How ordered or chaotic does the material appear to you? Low values indicate that the material's surface shows no regularities but rather is random or chaotic. High values mean that the surface has an ordered, regular structure.

2.4.3. Hardness

How hard or soft does the material appear to you? How much force would be required to change the shape of the material? Low values indicate that the surface feels soft; little force is required to change the shape of the material. High values indicate that it feels hard and cannot easily be deformed.