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Perception of the material properties of wood based on vision, audition, and touch

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ABSTRACT

Most research on the multimodal perception of material properties has investigated the perception of material properties of two modalities such as vision–touch, vision–audition, audition–touch, and vision–action. Here, we investigated whether the same affective classifications of materials can be found in three different modalities of vision, audition, and touch, using wood as the target object. Fifty participants took part in an experiment involving the three modalities of vision, audition, and touch, in isolation. Twenty-two different wood types including genuine, processed, and fake were perceptually evaluated using a questionnaire consisting of twenty-three items (12 perceptual and 11 affective). The results demonstrated that evaluations of the affective properties of wood were similar in all three modalities. The elements of "expensiveness, sturdiness, rareness, interestingness, and sophisticatedness" and "pleasantness, relaxed feelings, and liked–disliked" were separately grouped for all three senses. Our results suggest that the affective material properties of wood are at least partly represented in a supramodal fashion. Our results also suggest an association between perceptual and affective properties, which will be a useful tool not only in science, but also in applied fields.

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1. Introduction

When we purchase a product, we look beyond its material properties and examine it in various ways, such as by touching and tapping to hear the sound it makes. This "multimodality" method of examination is one aspect of the perception of material properties. In other words, the perception of material properties is not just visual, but can involve multiple senses just like time and space perception.

Previous research on the multimodal perception of material properties has involved the comparison of two modalities, or interactions between two modalities, such as vision and touch (e.g., Baumgartner, Wiebel, & Gegenfurtner, 2013; Lederman, Thorne, & Jones, 1986; Overvliet & Soto-Faraco, 2011), vision and audition (e.g., Fujisaki et al., 2014), audition and touch (e.g., Jousmäki & Hari, 1998; Zampini & Spence, 2005), and vision and action (e.g.,Buckingham, Cant, & Goodale, 2009). For example, Lederman et al. (1986) demonstrated that the relative weights between vision and touch were considerably altered by directing observers to judge different dimensions of the same textured surface. Strong emphasis was placed either on visual cues regarding the special density of raised dot patterns, or on tactile cues regarding roughness of the same surfaces. Baumgartner et al. (2013) showed that while material categorization performance was less consistent in the haptic condition than the visual one, ratings correlated highly between the two modalities. Overvliet and Soto-Faraco (2011) investigated how vision and touch contribute to the perception of naturalness in wood by comparing four psychophysical measurement methods. Their results show a high degree of consistency across these measurement methods, and that both vision and touch are highly correlated predictors of visuo-tactile perception of naturalness.

Fujisaki et al. (2014) recently found a strong interaction between audiovisual material perceptions; for example, an object appearing to be glass was perceived as transparent plastic when paired with the sound of a pepper being hit. They also found that material-category-likelihood ratings follow a multiplicative integration rule, while material-property ratings follow a weighted average rule; both can be interpreted as optimal Bayesian integration. For audition and touch, Jousmäki and Hari (1998) discovered the "parchment-skin illusion," which demonstrates that sounds synchronous with hand rubbing may strongly modify resulting

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tactile sensations. For example, enhanced high-frequency auditory feedback made palmar skin feel dry and almost like parchment paper. Zampini and Spence (2005) showed that perception of the crispness and staleness of potato chips can be affected by modifying sound produced during the biting action; for example, by varying the loudness and/or frequency of auditory feedback. For vision and action, Buckingham et al. (2009) investigated how visual cues of material properties affect how participants lift objects and perceive their weight, using the classic "material-weight illusion" (Seashore, 1899). They found that after a few lifts, participants scaled their forces to the actual weight of the blocks, implicitly disregarding the misleading visual cues; however, despite this rapid rescaling, participants experienced a robust material-weight illusion throughout the experiment.

Whereas much research has been conducted to investigate the perception of material properties using a single or two modalities, to our knowledge, there is no comprehensive comparison using three or more modalities of perception of material properties. Vision mainly provides us information about an object's surface, audition mainly an object's interior, and touch both surface and interior. Therefore, we expect that a comparison using the exact same materials, participants, and experimental procedures, will provide new information about the three different modalities (vision, audition, and touch), that cannot be understood by studying only a single or two modalities.

Another aspect of the perception of material properties is the breadth of concepts that are covered, including light reflection qualities such as "glossiness" (e.g., Fleming, Dror, & Adelson, 2003; Motoyoshi et al., 2007; Nishida & Shinya, 1998) and "translucency" (e.g., Fleming, Jäkel, & Maloney, 2011; Motoyoshi, 2010); acoustic qualities such as "sharpness" and "pitch" (e.g., Aramaki et al., 2011; Giordano & McAdams, 2006; Klatzky, Pai, & Krotkov, 2000; Lemaitre & Heller, 2012; Lutfi & Oh, 1997; Wildes & Richards, 1988); tactile qualities such as "roughness" and "hardness" (e.g., Guest & Spence, 2003; Lederman & Klatzky, 1987; Okamoto, Nagano, & Yamada, 2013; see also Klatzky & Lederman, 2010; Whitaker, Simoes-Franklin, & Newell, 2008 for review); aspects of materials themselves such as "cloth," "wood," "stone," "metal," and "pearl" (e.g., Fleming, Wiebel, & Gegenfurtner, 2013; Hiramatsu, Goda, & Komatsu, 2011; Sharan, Rosenholtz, & Adelson, 2009; Tani et al., 2014), and affective properties such as "prettiness," "fragility," "expensiveness," "liked and disliked," "naturalness," and "genuineness" (Fleming et al., 2013; Fujisaki et al., 2014; Overvliet & Soto-Faraco, 2011; Overvliet et al., 2008; Rozin, 2005). Thus, a wide range of concepts has been examined with respect to the perception of material properties.

The present study aimed to clarify the following questions, focusing on the "multimodality" and "breadth of covered concepts" of the perception of material properties:

[1] When separately evaluating material properties of the same target objects using vision, audition, and touch, would the judgments of affective properties of materials be similar if the target objects were the same, even if the sensory modalities were different? According to Gibson (1966), sensory stimulation is registered by a set of perceptual systems that are directly responsive to amodal invariants. For example, a fire is a source of four kinds of stimulation: sound, odor, heat, and light. Each type of stimulation specifies the same event, and each alone specifies the event. Gibson (1966) claims that the four kinds of stimulus information and the four perceptual systems are equivalent. Therefore, the perception of fire is simply the reception of information; the perception will be the same regardless of which system is activated, even though the conscious sensations will be different. Material perception involves a wide range of concepts, perceptual properties (such as brightness, pitch), and affective properties (such as prettiness, pleasantness) that are intermixed. Thus, from a Gibsonian point of view, we hypothesize that all three modalities will provide similar results for the perception of affective properties, which are considered to evoke relatively higher levels of processing.

[2] Is it possible to understand the relationship between different material properties adjectives by conducting an experiment that combines adjectives covering a broad concept? Can we understand which perceptual properties are related to which affective properties? If we can work towards systematically streamlining the wide range of concepts of material perceptions, it will be useful not only in science, but also in applied fields.

To approach the problem of "multimodalities," we chose wood as the target object from among numerous materials because it is familiar, has an abundance of variations, and contains much visual, auditory, and tactile information. To approach the problem of "breadth of covered concepts," 23 bipolar adjective pairs were used, most of which were selected from the previous literature (e.g., Cunningham et al., 2007; Fujisaki et al., 2014; Fujisawa, Iwamiya, & Takada, 2004; Gabrielsson & Sjogren, 1979; Osgood & Anderson, 1957; Solomon, 1958; von Bismarck, 1974a). We then conducted a material properties evaluation experiment with 50 participants regarding the same object, using the three modalities of vision, audition, and touch. Identical controlled conditions of evaluation items and participants were used.

2. Methods

2.1. Participants

Participants were 50 paid volunteers (aged 20–40 years old; 26 males, mean age = 28, SD = 4.75; 24 females, mean age = 29, SD = 4.42), who were blind to the study purpose. All had normal or corrected-to-normal vision and hearing, and were right-handed. The experiment was approved by the Institutional Review Board of the National Institute of Advanced Industrial Science and Technology (AIST), and was performed in accordance with the Declaration of Helsinki. All participants provided informed consent.

2.2. Selection of materials

Test specimens used in this study are shown in Fig. 1. Twenty-two varieties of materials, both fake and genuine, were used. Specifically, the materials included 14 varieties of genuine (pure) wood from different tree species, four varieties of genuine wood from 1 species (cedar) processed in different ways, and four varieties of fake wood (wood grain sheets attached to non-wood materials). All specimen sizes were identical: 60 mm wide, 120 mm long and 9 mm thick.

Fig. 1a shows the 14 varieties of real wood obtained from different tree species. Of the coniferous trees, three varieties were selected: cedar, Japanese cypress, and pine. Of the broadleaf trees, 11 varieties were selected: falcata (falcataria), poplar, lauan, maple, chestnut, walnut, cherry, oak, teak, guibourtia, and ebony. When selecting varieties, our intent was to include both coniferous and broadleaf trees, and evenly cover everything from extremely soft wood to extremely hard wood.

Fig. 1b shows frontal and cross-sectional views of the four test specimens chosen for the comparison of texture based on different processing methods: compressed materials (50% compression rate); heat-treated materials; non-combustible materials (with added chemicals); and heat-treated, non-combustible materials,

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