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Haptic aesthetics in the blind: A behavioral and fMRI investigation

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Abstract

Understanding perception and aesthetic appeal of arts and environmental objects, what is appreciated, liked, or preferred, and why, is of prime importance for improving the functional capacity of the blind and visually impaired and the ergonomic design for their environment, which however so far, has been examined only in sighted individuals.

This paper provides a general overview of the first experimental study of tactile aesthetics as a function of visual experience and level of visual deprivation, using both behavioral and brain imaging techniques. We investigated how blind people perceive 3D tactile objects, how they characterize them, and whether the tactile perception, and tactile shape preference (liking or disliking) and tactile aesthetic appreciation (judging tactile qualities of an object, such as pleasantness, comfortableness etc.) of 3D tactile objects can be affected by the level of visual experience. The study employed innovative behavioral measures, such as new forms of aesthetic preference-appreciation and perceptual discrimination questionnaires, in combination with advanced functional Magnetic Resonance Imaging (fMRI) techniques, and compared congenitally blind, late-onset blind and blindfolded (sighted) participants.

Behavioral results demonstrated that both blind and blindfolded-sighted participants assessed curved or rounded 3D tactile objects as significantly more pleasing than sharp 3D tactile objects, and symmetric 3D tactile objects as significantly more pleasing than asymmetric 3D tactile objects. However, as compared to the sighted, blind people showed better skills in tactile discrimination as demonstrated by accuracy and speed of discrimination. Functional MRI results demonstrated that there was a large overlap and characteristic differences in the aesthetic appreciation brain networks in the blind and the sighted. As demonstrated both populations commonly recruited the somatosensory and motor areas of the brain, but with stronger activations in the blind as compared to the sighted. Secondly, sighted people recruited more frontal regions whereas blind people, in particular, the congenitally blind, paradoxically recruited more 'visual' areas of the brain. These differences were more pronounced between the sighted and the congenitally blind rather than between the sighted and the late-onset blind, indicating the key influence of the onset time of visual deprivation.

Understanding of the underlying brain mechanisms should have a wide range of important implications for a generalized cross-sensory theory and practice in the rapidly evolving field of neuroaesthetics, as well as for 'cutting-edge' rehabilitation technologies for the blind and the visually impaired.

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Introduction

In the current social system information and resources are made most readily available to the visual sense. The societal infrastructure and exchange network are designed to optimize the freedom, functioning, and enjoyment of sighted people, facing the blind with exclusion from this network. For example, most products and technologies are usually developed and designed without reference to the implications for non-visual perception.

Society often lacks a sound understanding of the unique strengths blind people have, and the challenges they face in a world dominated by sight and of how to address those challenges effectively. In order to enhance the functional capacity of this special group we should understand how they perceive and enjoy the beauty of the world around them. In contrast to the rapidly growing interest in visual aesthetics, tactile aesthetics has been heavily neglected, and in particular, *experimental* studies in the visually deprived are lacking. This paper provides a general overview of the first experimental study of tactile aesthetics as a function of visual experience and onset time of blindness, using both behavioral and brain imaging techniques.

To understand aesthetics, what people *appreciate, love, like,* or *prefer*, and *why* they do so, is of prime importance in perceptual and applied sciences. *Tactile* aesthetics plays a dominant role in many aspects of life, for example, in product (e.g., smartphone) usability and preference for both the visually impaired and the sighted. In fact, the senses of vision, audition, olfaction, and touch are most often stimulated simultaneously and interact continuously (e.g., Gallace & Spence, 2011; Proulx et al., 2014). Our capacity to perceive aesthetic aspects of objects is essential for choosing preferred foods and products. Touch provides a closer, more sensuous and deeper knowledge of reality as compared to the vision (e.g., Montagu, 1971).

Though blind people rely primarily on touch for exploring and perceiving salient aspects of an object, very little research on tactile aesthetics has been conducted with this special population. One rare exception is work by Rubin (1976), who demonstrated that blind children usually preferred 3D scrap wood how they sculptures made by other blind children, rather than by sighted ones. Similarly, partially sighted and sighted children preferred products made by other partially sighted and sighted children respectively. Additionally, sighted participants appreciated abstract elements such as shape, texture and overall configuration of the products, but visually impaired youngsters rarely did so.

Palmer et al. (2013) proposed four aesthetic properties of *visual* object shape: the golden ratio, complexity and symmetry, contour curvature and categorical prototypes. For the visually deprived, the properties of *contour curvature, symmetry* and *complexity* can be of greater importance. However, to explain the preferred object properties, theories and research have exclusively focused on aesthetic preferences in the visual domain. For example, Berlyne (1971) famously theorized that *visual aesthetic preference* is an inverted-U function of arousal potential (innate capacity to induce arousal), and collative properties (e.g., object complexity) are the most important predictors of aesthetic preference (Martindale et al., 1990). A visual object with intermediate complexity of about 10 sides is usually preferred by both adults (Martindale et al., 1988) and children (Munsinger & Kessen, 1964). Preference effects of *complexity* show strong adaptation effects as a function of familiarization: people familiarized with simple visual stimuli later tend to prefer more complex visual stimuli, and those familiarized with complex visual stimuli tend later to prefer simpler visual stimuli (Tinio & Leder, 2009). Research on shape preferences using *symmetry* as the variable has shown that more symmetrical dot configurations are more easily processed perceptually and better remembered (Garner & Clement, 1963). In general, people tend to prefer visual shapes that are more symmetrical, although there are large and relatively stable individual differences in such effects (e.g., Palmer & Griscom, 2013).

Further research has demonstrated that *sighted* people tend to like visual objects with *curved* contours more than similar objects with *sharp* contours (Bar & Neta, 2006; Vartanian et al., 2013; cf. Kohler, 1929). This is the case for both abstract shapes and recognizable objects (Silvia & Barona, 2009) as sharp contours appear to be more threatening than curved contours (Bar & Neta, 2006, 2007). Research on aesthetic preferences for 3D shapes has further shown that spheres are rated as more pleasant than cubes, and curved shapes (e.g., cylinder) as more pleasant than angular shapes (e.g., cones) in both vision and touch (Etzi et al., 2012). Moreover, triangle and rhombus are preferred even less when explored haptically, and cubes are preferred less when explored unimanually than when explored bimanually.

These findings provide initial insights into the cognitive processing of both *visual* and *tactile* aesthetics; however, they are restricted to the capacity and interest of the *sighted* population. They do not tell anything about the role visual experience plays in the aesthetic perception of objects. Basic perceptual research has shown that the lack of visual experience might impair the integration of multisensory information during spatial tasks (e.g. Pasqualotto & Newell, 2007). In particular, vision is better suited for shape processing than touch (e.g., Klatzky et al., 1989), and non-visual modalities might not be able to fully compensate for the lack of visual experience as in the case of congenital blindness (Pasqualotto & Proulx, 2012). On the contrary, other research has demonstrated that blind participants have superior skills in tactile (Braille) letter recognition (Craig, 1988), tactile orientation discrimination (Goldreich & Kanics, 2003; Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000) and other forms of tactile acuity tasks (Legge, Madison, Vaughn, Cheong, & Miller, 2008), as compared to the sighted participants. Cross-modal plasticity research has shown that early blind participants activate occipital cortex during Braille reading (Cohen et al., 1999; Sadato et al., 2002; Wittenberg, Werhahn, Wassermann, Herscovitch, & Cohen, 2004), whereas the late-onset blind or sighted participants show deactivation (Sadato et al., 2002) or less activation (Sadato et al., 1996; Wittenberg et al., 2004) of this region. Early and late-onset blind also showed opposite effect in training of tactile face perception (Mei and Likova, 2012). It has further been shown that through the unique Cognitive-Kinesthetic training (Likova, 2012) totally blind – both with acquired and congenital blindness, as well as blindfolded-sighted, people are all able to rapidly learn to recognize and appreciate complex shapes of raised-line objects, memorize them in detail, and use these detailed memory representations to guide free-hand drawing movements, thus reproducing the sensed images from memory without any vision involved. The Cognitive-Kinesthetic training has also shown that heightened haptic experience can foster the acquisition of higher-order spatiomotor skills in the blind, such as the higher-order drawing skills causally linked to dramatic brain reorganization (Likova, 2013, 2014, 2015, 2017; Cacciamani & Likova, 2017). In the context of V1 reorganization as a function of visual deprivation, an important finding was that after the Cognitive-Kinesthetic training the congenitally and late-onset blind, as well as the blindfolded-sighted groups activated the central ~10 deg, but deactivated the peripheral V1 (Likova, 2014). The deactivation was strongest in the blindfolded-sighted group (Likova, 2013). These studies led to the proposal that the primary visual cortex may operate in the "universal language of modality-independent space" (Likova et al., 2011).

Does the brain reorganization driven by the lack of visual experience lead to any differences in the aesthetic perception and appreciation of tactile objects and the brain mechanisms associated with such functioning in the blind? The knowledge we currently have cannot directly answer this kind of questions. However, there have been some recent developments in the understanding of aesthetics in the haptic domain. For example, a three-level (low-, mid- and high-level) analysis model for haptic aesthetics in the sighted and its implications for design has been proposed by Carbon and Jakesch (2013). The same group has also investigated the effect of mere exposure in the haptic domain (Jakesch & Carbon, 2012), and in collaboration with other researchers, studied the influence of top-down processes on tactile appreciation and compared it to visual appreciation (Jakesch et al., 2011). All these were important steps beyond visual aesthetics, but, still entirely focused on the sighted population.

In order to gain further understanding of haptic aesthetics, we examine here the effect of the level of visual system development at the time of loss of vision on haptic/tactile aesthetics by studying congenitally blind, late-onset blind and blindfolded-sighted individuals.

In addition to the behavioral assessments, a second key purpose of the present study was to uncover the neural basis of tactile aesthetics in the blind. In order to achieve this end, we take in the experiments the behavioral measures of, as well as examine the causal role of brain areas for, tactile aesthetics. Research to date has demonstrated neural correlates of visual aesthetics (Cela-Conde et al., 2004; Kawabata, & Zeki, 2004; Vartanian, & Goel, 2004). For example, in a study by Kawabata and Zeki (2004), different types of paintings activated distinct and specialized visual areas of the brain. Here, we examine the aspects of tactile aesthetics in the blind and blindfolded-sighted humans using functional Magnetic Resonance Imaging (fMRI), as a first step to experimentally inform the development of a theory or model of tactile neuroaesthetics.

Methods and Results

Experiment 1: Behavioral Assessment of Aesthetic Appreciation

Methods

Participants

18 congenitally blind (age: 30 – 75, Mean = 44.55, SD = 14.64; male: 8, female: 10), 14 late-onset blind (age: 25 – 46, Mean = 35.52, SD = 6.04; male: 7, female: 7), and 19 blindfolded sighted healthy adults (age: 22 – 69, Mean= 42.09, SD=16.57; male: 4, female: 15) voluntarily participated in this behavioral experiment. There were one left-handed participant and one ambidextrous participant in the congenitally blind and the sighted groups respectively. There were no ambidextrous but five left-handed participants in the late-onset blind group. The visual acuity of the blind participants ranged from <20/500 to NLP (no light perception) and that of the sighted participants was normal or corrected to normal. The late-onset blind participants had a history of full vision for a period of 7 months to 35 years whereas congenitally blind participants never had full vision. Individuals having cognitive impairment, neuropathy of the hands or fingers and hearing loss were not included in this experiment.

Materials

1. Tactile stimulus batteries

We developed two tactile stimulus batteries. The battery used in the first experimental condition, Condition 1, comprises nine pairs of sharp and rounded 3D wooden geometric shapes (‘*sharp vs curved or rounded’*), while in Condition 2 the battery was made up of ten pairs of unfamiliar 3D plastic shapes (‘*symmetric vs asymmetric’*). The overall object dimensions in Condition 1 ranged from 4.5 cm × 3.7 cm × 3.3 cm to 7.6 cm × 5 cm × 5 cm, and in Condition 2 - from 6.1 cm × 5.7 cm × 2.5 cm to 9.2 cm × 5.7 cm × 5.0 cm. The objects of each stimulus pair were approximately of equal size.

Condition 1: Sharp vs curved or rounded 3D battery

Figure 1. Examples of 3D wooden geometric shapes from our ‘*sharp vs curved*’ stimulus battery.

Condition 2: Symmetric vs asymmetric 3D battery

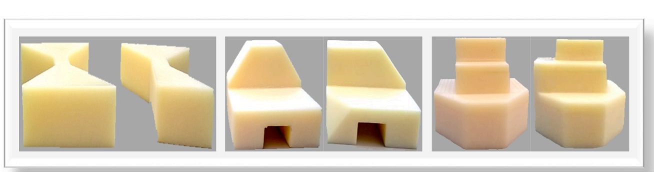

Figure 2. Examples of 3D plastic geometric shapes from our ‘*symmetric vs asymmetric*’ stimulus battery.

2. Tactile preference - appreciation - discrimination questionnaire

Reviewing the relevant literature (e.g., Ackerley et al., 2004; Gallace & Spence, 2011; Guest et al., 2011) we designed a set of 14 questions to measure three behavioral constructs using a pairwise comparison method. These constructs are: i) ***tactile preference*** (one question; which of the two stimuli do you prefer?), ii) ***tactile aesthetic appreciation*** (twelve questions: which of the two stimuli is more 1) evocative, 2) calming, 3) comfortable, 4) desirable, 5) enjoyable, 6) exiting, 7) pleasant, 8) relaxing, 9) sensual, 10) appealing, 11) soothing, 12) thrilling; each question was asked and answered separately), and *iii)* ***basic tactile discrimination*** (one question; Condition 1: which of the two stimuli is sharper; Condition 2: which of the two stimuli is more symmetrical?).

Procedure

Participants were tested individually in two different experimental conditions (see above) in a single sitting with a time interval of 5 min between the conditions. Nine pairs of 3D tactile geometric shapes (*sharp vs curved or rounded;* e.g., sphere vs pyramid, cone vs pyramid etc.) were presented in pseudorandom order in the first condition, and ten pairs of unfamiliar 3D tactile shapes (*symmetric vs asymmetric*) were presented in a similar fashion in the second condition. The task in both conditions was to explore haptically and compare the members of each stimulus pair with two hands for 60 sec, and respond to the set of 14 questions using a paired comparison paradigm. The stimulus preference questions were followed by the aesthetic appreciation and tactile discrimination questions. This order was chosen in order to avoid any potential influence of aesthetic appreciation or tactile discrimination on participant’s preference response. It took about 1 hour and 15 min for each participant to complete both experimental sessions.

Results

Tactile stimulus preference

Each participant’s choice for a sharp/asymmetric stimulus was scored as ‘0’ and that for a curved/symmetric stimulus as ‘1’. Then each participant’s relative preference index, or bias index, was calculated using the following formula:

$$Bias = \frac{Number\ of\ 1s - Number\ of\ 0s}{Sum\ of\ the\ number\ of\ 1s\ and\ the\ number\ of\ 0s} \times 100$$

The bias index can range from –100 to +100, and indicates relative preference for a particular stimulus over the comparison one. A higher absolute value of the bias (i.e., a larger deviation from ‘0’) indicates a stronger preference for that object.

Data showed that most participants preferred curved and symmetric objects although there were large individual differences (Figure 3). A positive value on the Y-axis indicates relative preference for a curved (Figure 3A) or symmetric (Figure 3B) object and a negative value indicates relative preference for a sharp (Figure 3A) or for asymmetric (Figure 3B) object. Analysis of data in a one-way ANOVA using *visual experience level* as the independent variable, and *relative preference index* or *bias index* as the dependent variable

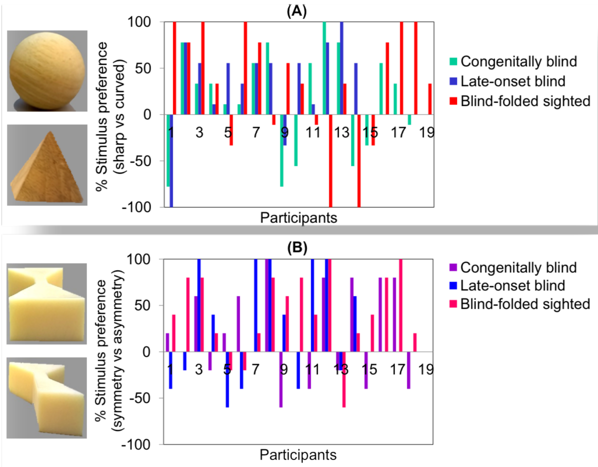

Figure 3. Percentages of tactile stimulus preference in three participant groups. Left panels show example pairs from the compared stimulus categories. Right panels provide quantitative assessment of stimulus preference. (A) Sharp vs curved 3D objects. (B) Symmetric vs asymmetric 3D objects.

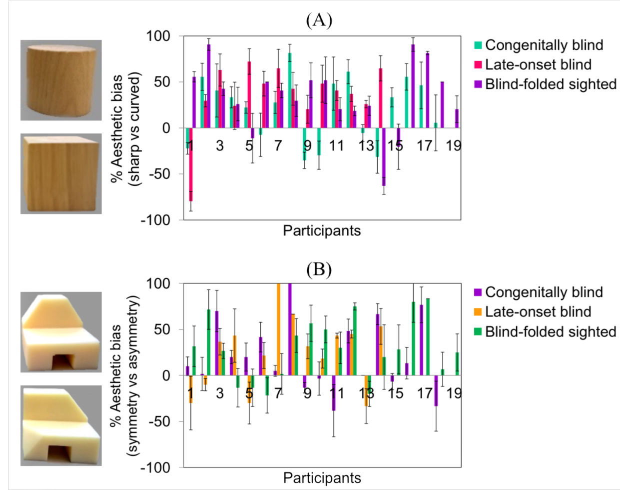

Figure 4. Percentages (Mean ± SEs) of aesthetic bias in three participant groups. **Left** panels show example stimulus pairs from the compared categories. **Right** panels provide quantitative assessment of aesthetic appreciation. (**A**) Sharp vs curved stimuli, (**B**) Symmetric vs asymmetric stimuli. A positive value on the Y-axis indicates relative aesthetic bias for a curved or symmetric object and a negative value indicates relative aesthetic bias for a sharp or asymmetric object. Error bars reflect standard errors of the mean (calculated for each participant over the nine or ten object pairs).

showed no significant differences among the three participant groups.

One interesting observation is that the *within-group proportions* of individuals showing a *preference* for curved or rounded 3D tactile objects were in the order of late-onset blind (85.71%) > blindfolded-sighted (68.42%) > congenitally blind (66.67%) (Figure 3A) whereas, the *within-group proportions* of individuals showing a *preference* for symmetrical objects were in the order of blindfolded-sighted (84.14%) > congenitally blind (66.67%) > late-onset blind (57.14%) (Figure 3B). These results further indicate that *as compared to the blindfolded-sighted*, a greater proportion of the blind has a *preference* for sharp 3D and asymmetric 3D tactile objects over the comparison ones.

Aesthetic appreciation

Each participant's aesthetic bias for each stimulus pair in each of the two experimental conditions was calculated using the same formula as above. To do so, we counted how many times a stimulus was chosen or was not chosen while *judging on a set of 12 aesthetic properties*. There were 9 pairs of tactile stimuli in Condition 1 and 10 pairs of tactile stimuli in Condition 2. Thus, for each participant, we obtained 9 aesthetic bias indexes in Condition 1, and 10 aesthetic bias indexes in Condition 2. Similarly to the stimulus preference index, an *aesthetic bias index* can also range from –100 to +100, indicating the relative *aesthetic appreciation* for a particular stimulus over the comparison one. Consistent with the stimulus preference results in Condition 1, data showed that most participants appreciated *curved or rounded* and *symmetric* objects as tactilely more aesthetic than sharp and asymmetric objects respectively although there were large individual differences in the level of aesthetic appreciation (Figure 4). There were also no significant differences among the groups when data were analyzed in a one-way ANOVA using visual experience level as the independent variable and aesthetic bias index as the dependent variable.

Interestingly, the within-group proportions of individuals who appreciated curved or rounded 3D tactile shapes as tactilely more aesthetic were in the order of blindfolded-sighted (94.74%) > late-onset blind (92.86%) > congenitally blind (77.87%) (Figure 3A) whereas, the within-group proportions of individuals who appreciated symmetrical shapes ***as tactilely more aesthetic were in the order of*** blindfolded-sighted (89.47%) > congenitally blind (83.34%) > late-onset blind (71.43%) (Figure 3B). These results further indicate that *as compared to the blindfolded-sighted****,*** a greater proportion of the blind appreciated sharp 3D and asymmetric 3D shapes as ***tactilely*** more aesthetic than the comparison ones.

Tactile discrimination

The tactile discriminability of sharpness vs curvature and symmetry vs asymmetry was close to 100% for most of the participant groups separated by gender, with the lowest discriminability being for symmetry vs asymmetry discrimination in congenitally blind males, at 91%.

To summarize, there was no significant difference in tactile discrimination (sharpness/curvedness, symmetry/asymmetry) between the three categories of participants. All groups, however, on average, exhibited significantly higher preference and aesthetic appreciation bias for a curved or rounded over a sharp, and for a symmetric over an asymmetric tactile 3D shape; this effect was strongest in the blindfolded-sighted group

Experiment 2. Brain imaging of aesthetic appreciation

To get insights into the brain processing of aesthetic judgement, we designed a second experiment using functional Magnetic Resonance Imaging (fMRI).

Methods

Participants

5 congenitally blind (age: 23 – 71, Mean= 38.47, SD=18.94; male: 1, female: 4), 5 late-onset blind (age: 58 – 71, Mean=64.44, SD=6.41; male: 2, female: 3), and 5 blindfolded sighted healthy adults (age: 27 – 59, Mean=42.59, SD=14.02; male: 3, female: 2) voluntarily participated in this experiment. There was only one left-handed participant in each group. The visual acuity of the congenitally blind participants ranged from LP (light perception) to NLP (no light perception) and that of the late-onset blind participants ranged from <20/500 to LP, with a normal or corrected to normal vision of the sighted participants. As in Experiment1, individuals having cognitive impairment, neuropathy of the hands or fingers and hearing loss were not included in this experiment.

fMRI design and procedure

Two experimental conditions were run. In **Condition 1** a battery of 6 sharp and 6 curved/rounded 3D tactile stimuli was used, while in **Condition 2** a battery of 6 symmetric and 6 asymmetric stimuli was used. In each of 8 scans, six 20 sec task periods were separated by 20 sec rest periods. The objects in each scanning session were presented in a pseudorandom order (rather than in a paired fashion) using an fMRI-compatible multi-compartment stimulus box developed for this study (see Figure 6). Two questions were asked using a dual ABBA design in each of the two conditions (see Figure 5). The scan order was 1A, 1B, 1B, 1A, 2A, 2B, 2B, 2A and fixed across sessions. In Condition 1A & 1B, there were always 3 sharp and 3 curved/rounded objects, and in Condition 2A & 2B, there were always 3 symmetric and 3 asymmetric objects. Within a session, the same random sequence of objects was used with two replications of 1A, 1B, 2A, 2B. However, object sequences were randomized across participants. In the **A-scans** under each of the two conditions, each participant's task was to explore the shapes, taking one object at a time (starting from the left of the stimulus box), with two hands, and indicate by a button press whether the shape was **pleasing**. In the **B-scans**, each participant indicated whether the explored shape was sharp (Condition 1) or whether it was symmetric *(Condition 2)*.

Condition 1

1A: Is the shape pleasing? (Q1)

1B: Is the shape sharp? (Q2)

Condition 2

2A: Is the shape pleasing? (Q1)

2B: Is the shape symmetric? (Q2)

Each haptic exploration block began with an audio cue of one of the questions above, and the end of the exploration time was cued by the audio command *"Stop and press a button*". The left button on the Response Box was used for "Yes" and the right button for "No". Each participant was instructed to use the left hand to leave the already explored object in the large compartment in the back of the stimulus box (see Figure 6), and the right hand to press the button.

Experimental Design

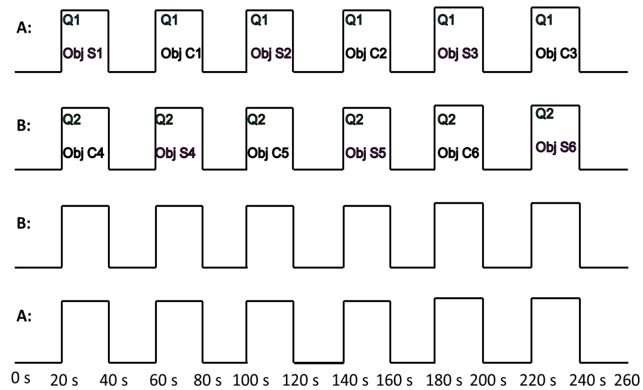

Figure 5. Dual ABBA design of the experiment. Condition 1, investigating sharp (Si) vs curved (Ci) 3D objects, is illustrated. The same design was employed in Condition 2 but using asymmetric vs symmetric 3D objects.

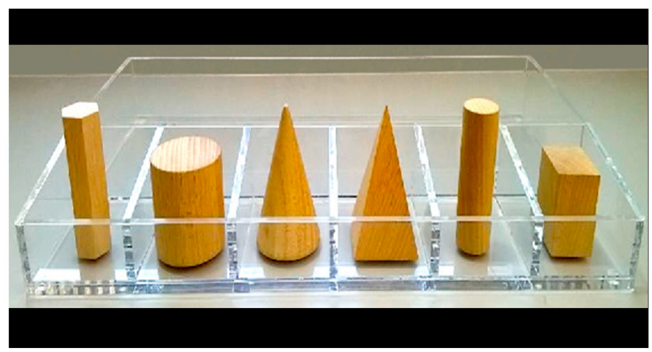

Figure 6. Examples of sharp and curved 3D geometric stimuli, placed into our MRI-compatible multi-compartment box, in Condition 1.

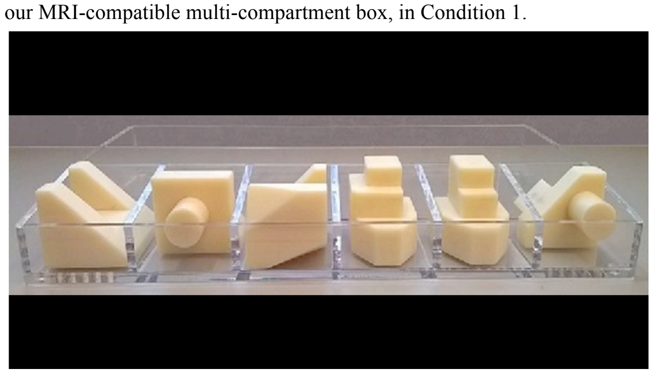

Figure 7. Examples of symmetric and asymmetric unfamiliar 3D stimuli, placed into our MRI-compatible multi-compartment box, in Condition 2.

Brain imaging data acquisition and pre-processing

Functional MRI data were collected on a Siemens Prisma 3T magnet equipped with a 64-channel head coil (Siemens Healthcare, Erlangen, Germany). BOLD responses were obtained using an EPI acquisition (TR = 2 sec, TE = 30 msec, flip angle = 45^o, voxel size = 2.5 x 2.5 x 2.5 mm) consisting of 54 axial slices extending across the whole brain. Pre-processing was done using FSL (FMRIB Analysis Group, Oxford, UK), and included slice-time correction and two-phase motion correction, consisting of both within-scan and between-scan 6-parameter rigid-body corrections. To facilitate segmentation and registration, a whole-brain high-resolution T1-weighted anatomical scan was also obtained for each participant (voxel size = 0.8 x 0.8 x 0.8 mm). White matter segmentation in this T1 scan was done using FreeSurfer (Martinos Center for Biomedical Imaging, Massachusetts General Hospital) and gray matter was generated with the mrGray function in the mrVISTA software package (Stanford Vision and Imaging Science and Technology, Palo Alto, USA). The Stanford package mrVISTA allows us to estimate the neural activation amplitudes for each task within respective regions of interest (ROIs) using a standard general linear model (GLM) procedure for each task regressor applied to the average signal across all voxels within each ROI. Cortical activation maps across subjects were compared by transforming individual data to a common average surface using spherical surface registrations from Freesurfer.

Results

Comparative fMRI analysis of aesthetic appreciation

As an initial overview of the accumulated fMRI data, here we restrict our focus on the large-scale inter-group comparisons of the brain networks for aesthetic judgment. The surface averaged activation maps in Figure 8 represents the differences between each two of the three participant groups: i) left column –blindfolded-sighted vs late-onset blind; ii) middle column - blindfolded-sighted vs congenitally blind; iii) late-onset blind vs congenitally blind. The primary regions of activation as apparent from these difference maps are the well-established regions of the reward pathway, including anterioventral cortex adjacent to the hypothalamus and dorsomedial thalamic nucleus and the nucleus accumbens, together with the ventro-medial pre-frontal and the orbitofrontal cortex.

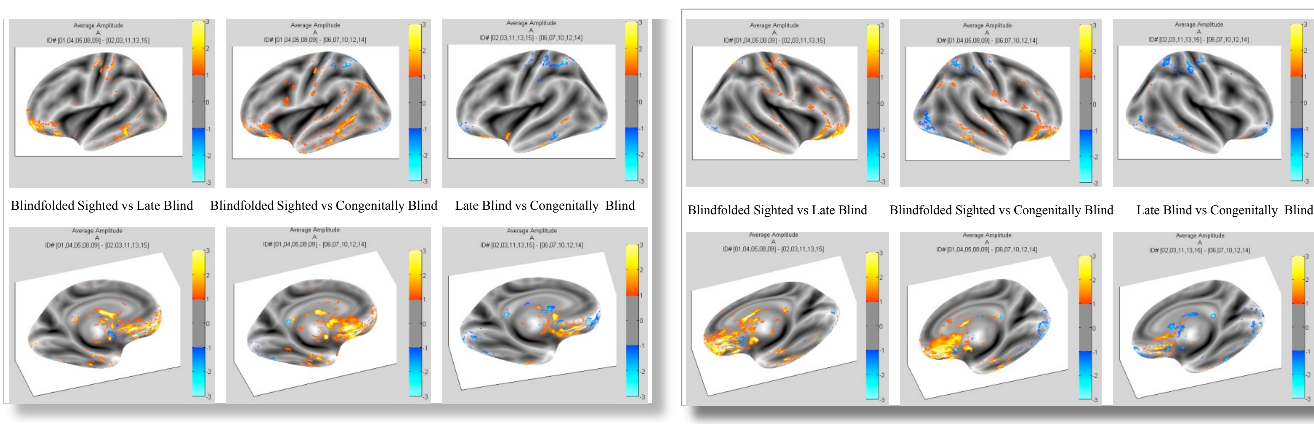

Figure 8. Difference maps of brain activation during aesthetic appreciation for three participant groups. **Left panel:** Lateral view (upper panel) and medial view (lower panel) of the left hemisphere. **Right panel:** Lateral view (upper panel) and medial view (lower panel) of the right hemisphere. In each panel, the brain activation difference between ***blindfolded-sighted and late-onset blind*** participants is shown in the left column; the activation difference between ***blindfolded-sighted and congenitally blind*** participants is shown in the middle column, and the activation difference between ***late-onset blind and congenitally blind*** participants is shown in the right column. The yellowish or reddish color indicates brain areas that were more strongly activated in the first group of the respective comparison (e.g., blindfolded sighted in the comparison "Blindfolded Sighted vs Congenitally Blind"), and the bluish color indicates areas that were more strongly activated in the second group of the respective comparison (e.g., congenitally blind in the comparison "Blindfolded Sighted vs Congenitally Blind").

There is also a region of consistent activation in the middle temporal gyrus, typically involved in object processing. A gross intergroup comparison of the difference maps indicates that both sighted and blind people commonly recruited the somatosensory and motor areas of the brain, but with a stronger activation in the blind as compared to the sighted. Secondly, sighted people recruited more frontal areas (yellowish or reddish) whereas blind people, in particular, the congenitally blind recruited more 'visual' areas (bluish) of the brain. Thus there were both a large overlap and characteristic differences across groups of different levels of visual experience, and respectively, across different levels of development of the visual system. The detailed analysis of these data, however, is beyond the scope of this overview.

Concurrent behavioral results

Haptic aesthetic appreciation

Analysis of the behavioral data (button-press responses to the aesthetic appreciation question "Is this shape pleasing?", which was asked in the scanner) was carried out by a one-way repeated measures ANOVA, taking proportion of the stimuli judged as aesthetically pleasing as the dependent variable and stimulus sharpness/curvedness as the independent variable. The results support our findings from the large-scale behavioral study in Experiment 1, which was run on a different sample.

Because there was no significant effect of visual experience on aesthetic appreciation, we collapsed the data across participant groups and found that irrespective of visual experience participants appreciated curved/rounded tactile stimuli as significantly and aesthetically more pleasing than sharp tactile stimuli ($F(1, 12)=10.53$, $p=0.007$; Figure 9). Similarly, they appreciated symmetric tactile stimuli as significantly and aesthetically more pleasing than asymmetric tactile stimuli ($F(1, 12)=10.51$, $p=0.007$; Figure 10).

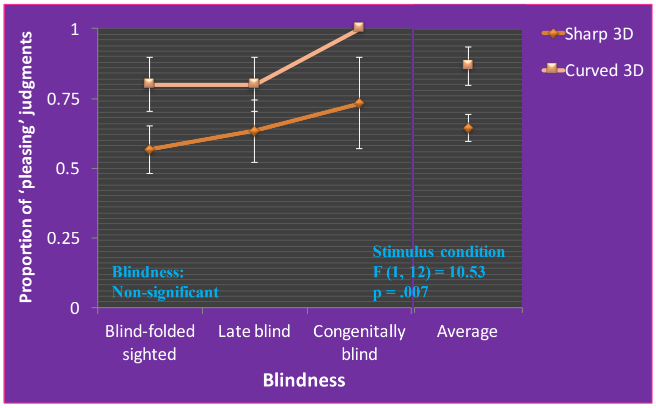

Figure 9. Aesthetic appreciation of sharpness vs curvedness/roundness in three visual experience groups.

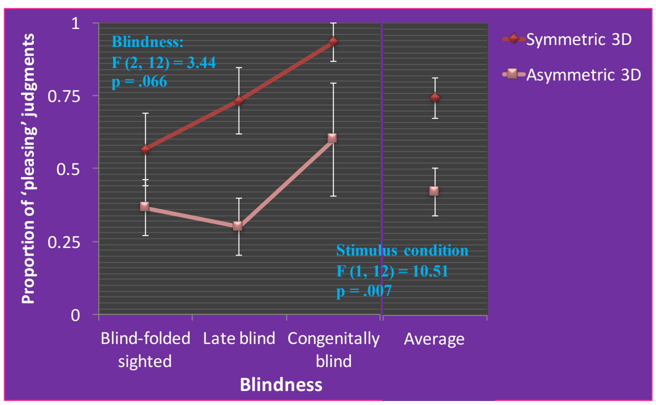

Figure 10. Aesthetic appreciation of symmetry vs asymmetry in three visual experience groups.

Tactile discrimination

Analysis of sharpness and symmetry detection data in a one-way ANOVA, taking sharpness detection or symmetry detection as the dependent variable and visual experience level as the independent variable, further demonstrated that there was no significant effect of visual experience on sharpness detection, but on symmetry detection ($F(2, 12)= 6.11$, $p=0.0015$; Figure 11, left column–lower panel). Moreover, reaction time (RT) data showed that visual experience has significant effect on the speed at which participants were able to detect sharpness or symmetry of an object (sharpness detection: $F(2, 12)=4.903$, $p=0.028$, Figure 11, right column–upper panel; symmetry detection: $F(2, 12)=3.75$, $p=0.05$, Figure 11, right column–lower panel). Posthoc analyses of RT data revealed that congenitally blind participants were significantly faster at sharpness (Bonferroni, $p=0.036$) and symmetry (LSD, $p=0.026$) detection. However, the effect of stimulus or task condition on the response speed, demonstrated by a one-way repeated measures ANOVA, was nonsignificant.

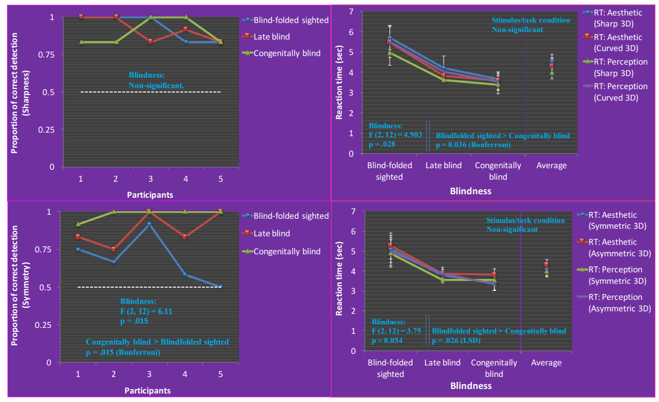

Figure 11. Correctness in sharpness and symmetry detection (left panels) and reaction time (RT) taken in such detection and aesthetic appreciation tasks (right panels) in three groups with different visual experience.

To summarize, as compared to the sighted, blind people, especially those who were congenitally blind, showed better skills in tactile discrimination as demonstrated by accuracy and speed of discrimination. Combining the results of behavioral and fMRI investigation it appears that the blind and sighted people do not typically exhibit a difference in aesthetic appreciation, but they do show differences in areas of the brain involved in such function. Although both the populations commonly recruit the somatosensory and motor areas of the brain, sighted people recruit more frontal whereas blind people paradoxically recruit more classically visual brain areas.

Discussion and Conclusions

This paper provides a general overview of the first experimental study of tactile aesthetics as a function of visual experience and onset time of visual deprivation, using a combination of behavioral and brain imaging techniques.

Behavioral study: Experiment 1

As demonstrated, all the three visual experience groups exhibited significantly higher preference and aesthetic bias for curved/rounded 3D tactile geometric objects over sharp 3D tactile geometric objects, and for symmetric 3D tactile shapes over asymmetric 3D tactile shapes. These are the first findings in the tactile modality and are in line with prior findings in the visual modality which have shown that people prefer curved over sharp visual objects (Bar & Neta, 2006, 2007; Gómez-Puerto et al., 2015; Guthrie & Wiener, 1966; Silvia & Barona, 2009; Vartanian et al., 2013), and symmetric over asymmetric visual objects (Cárdenas & Harris, 2006; Little & Jones, 2003; Shepherd & Bar, 2011).

Interestingly, content analysis of our data demonstrated that both the blind and the sighted participants characterized the sharp or asymmetric 3D tactile shapes by more emotionally intense attributes as compared to the curved/rounded or symmetric shapes. This result suggests that sharp or asymmetric 3D tactile shapes may have inherent, possibly ecologically-based, capacity to produce a greater response in the brain areas engaged in emotion processing as compared to the curved/rounded or symmetric shapes. This difference is partly supported by the prior findings in the visual modality, which revealed that sharp visual stimuli produce an increased activation in the amygdala as compared to the curved visual stimuli (Bar & Neta, 2007).

fMRI Study: Experiment 2

Consistent with the results of the larger-scale behavioral study in Experiment 1, the behavioral data from the fMRI study in Experiment 2 showed that both the blind and the sighted have a higher aesthetic appreciation for curved/rounded 3D and symmetric 3D tactile shapes than for sharp 3D and asymmetric 3D tactile shapes. However, this fact does not necessarily mean that there is no difference in the underlying brain network. To investigate experimentally, for the first time, the neural correlates of tactile aesthetics, and effect of visual experience on it, we conducted an fMRI study comparing congenitally blind, late-onset blind and blindfolded-sighted participants.

In general, the fMRI data demonstrated a large overlap and characteristic differences of the aesthetic appreciation brain networks in the blind compared to the (blindfolded) sighted. Although both populations commonly recruited the somatosensory and motor areas of the brain, sighted people recruited more frontal areas whereas blind people – in particular, the congenitally blind – (paradoxically!) recruited more classic 'visual' areas. Aesthetic appreciation requires involvement of higher order cognitive functions (Cela-Condea et al., 2013). Thus, the frontal areas, considered to be responsible for aesthetic judgment functions, were strongly activated during aesthetic appreciation in the (blindfolded) sighted individuals. Specifically, most of the *reward network* established in *visual* experimental paradigms in the sighted, such as the ventro-medial pre-frontal cortex (vmPFC), orbito-frontal cortex (OFC), anterior cingulate (ACC), nucleous accumbens (Nacc) were exclusively, or more activated in the (*blindfolded*) sighted than in either of the two blind groups. In contrast, the activation in the 'visual' cortex typically exhibited a gradient from being the strongest in congenitally blind to being the weakest in the blindfolded-sighted; similarly, somatosensory and motor areas showed stronger activation in the congenitally blind than in the late-onset blind and sighted individuals (Figure 8). Here, we theorize that these results reflect deprivation-driven reorganization of the visual cortex to 'serve' the aesthetic judgment process in the blind. This 'service' can range from providing a holistic representation of the object shape through the spatio-temporal integration of the haptic input over the time of exploration in order to feed it into the aesthetic judgement regions; or instead, the visual cortex resources may be used in a higher-order fashion.

The data also indicate that cortical functional reorganization in the blind is a function of not only duration and level of visual deprivation, but also of the onset time of such deprivation, which reflects *the level of development of the visual system* reached *before* being deprived. Taken together, these results show that visual deprivation or absence of typical visual experience drives plastic reorganization in the neural substrate involved in haptic aesthetics. The detailed analysis of these data, however, is beyond the scope of the current overview.

Concurrent behavioral results showed that as compared to the sighted, blind people have better skills in tactile shape discrimination as demonstrated by accuracy and speed of discrimination. This finding is consistent with prior research that has demonstrated that blind Braille readers have superior skills in tactile (Braille) letter recognition (Craig, 1988), tactile orientation discrimination (Goldreich & Kanics, 2003; Van Boven et al., 2000) and other forms of tactile acuity tasks (Legge et al., 2008), as compared to the sighted readers. Again, this perhaps can be linked to the findings that heightened haptic experience – in conjunction with appropriate cognitive involvement – can rapidly foster acquisition of higher-order spatiomotor (and memory) skills in the blind, such as through the Cognitive-Kinesthetic memory-drawing training (Likova, 2013, 2014, 2017, 2018).

The findings reported in this overview, represent the first experimental step towards understanding of the brain mechanisms of tactile or haptic aesthetics. They should have a wide range of important implications for both, the development of a generalized cross-sensory theory and the practice in the rapidly evolving field of neuroaesthetics, as well as being potentially of practical use in the design of the environment, objects and aiding devices for the blind and the visually impaired people.

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