

# 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 perceptual and aesthetic preference-appreciation scales, 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 aesthetics appreciation brain networks in the blind and the sighted. Although both populations commonly recruited the somatosensory and motor areas of the brain, sighted people recruited more frontal regions whereas blind people paradoxically recruited more classically visual brain areas. 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 time of onset of visual deprivation.

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

## 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 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 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* are of greater importance. Berlyne (1971) famously discovered that *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). An 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 stimuli later tend to prefer more complex stimuli, and those familiarized with complex stimuli tend later to prefer simpler 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 shapes that are more symmetrical, although there are large and relatively stable individual differences in such effects (e.g., Palmer & Griscom, 2013).

Recently, it has been demonstrated that *sighted* people tend to like 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. Research on aesthetic preferences of 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 some initial insights into the cognitive processing of *visual* and *tactile* aesthetics, restricted, however, the *sighted* population. Thus, the question of whether the visual experience plays any role in aesthetic perception of objects has not been addressed previously. 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); thus, it has been often assumed that the lack of visual experience might deteriorate our capacity to judge aesthetics of object shapes. On the contrary, it has been shown that through the unique Cognitive-Kinesthetic training (Likova, 2012) totally blind, as well as blindfolded-sighted, people are all able to rapidly learn to recognize and appreciate complex shapes of raised-line faces and 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).

Does the brain reorganization driven by the lack of visual experience lead to significant differences in the aesthetic experience and brain mechanisms in the blind? The present study investigates these

questions. A three-level (low-, mid- and high-level) analysis model for haptic aesthetics in the sighted and its implications for design was proposed by Carbon and Jakesch (2013). The same group also investigated the effect of mere exposure in the haptic domain (Jakesch and 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, however, entirely focused on the sighted population. We examine here the effect of the level of visual system development on 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 using functional Magnetic Resonance Imaging (fMRI), as a first step to experimentally inform the development of a tactile neuroaesthetic model or theory.

## Methods and Results

### Experiment 1: Behavioral Assessment of Aesthetic Appreciation

#### 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 had 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 first experimental condition, Condition 1, comprises nine pairs of sharp and rounded 3D wooden geometric shapes (*'sharp vs curved'*), 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 of approximately equal size.

### Condition 1: Sharp vs curved 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 scale

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) reference** (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?).

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 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 was 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.

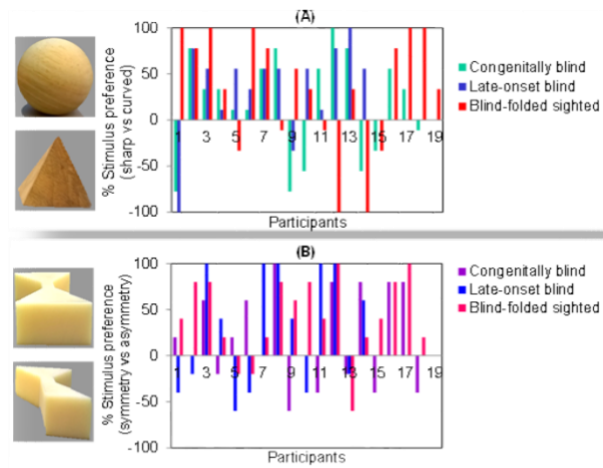
## Results

### 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:

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

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 (Figure 3), although there were large individual differences. An ANOVA analysis using *visual experience level* as the independent variable, and *relative preference index* or *bias index* as the dependent variable showed no significant differences among the three subject groups.



**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.

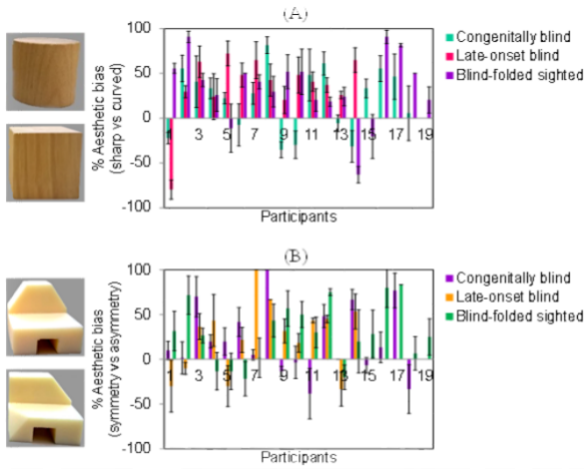
Relative preference index was calculated using the formula above. A positive value on the Y-axis indicates relative preference for a curved (in A) or symmetric (in B) object and a negative value indicates relative preference for a sharp (in A) or for asymmetric (in B) object.

One interesting observation is that the *within-group proportions* of individuals showing a *preference* for rounded 3D tactile objects were in the order of late-onset blind > blindfolded-sighted > congenitally blind; specifically 85.71% vs 68.42% vs 66.67%, respectively (Figure 3A). Whereas, the *within-group proportions* of individuals showing a *preference* for symmetrical objects were in the following order: blindfolded-sighted > congenitally blind > late-

onset blind >; specifically, 84.14% vs 66.67%, vs 57.14%, respectively (Figure 3B).

### 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 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 appreciating *curved* and *symmetric* objects as tactilely more aesthetic than sharp and asymmetric objects respectively (Figure 4), although there were large individual differences in the level of aesthetic appreciation. There were also no significant differences among the groups when data were analyzed in an ANOVA using visual experience level as the independent variable and aesthetic bias index as the dependent variable.



**Figure 4.** Percentages (Mean  $\pm$  SEs) of aesthetic bias in the three participant groups. **Left** panels show examples of 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).

Interestingly, the within-group proportions of individuals appreciating aesthetically rounded 3D tactile shapes were in an order of blindfolded-sighted > late-onset blind > congenitally blind; specifically 94.74% vs 92.86% vs 77.87%, respectively (Figure 3A). Whereas, the within-group percentage of individuals appreciating aesthetically symmetrical shapes were: blindfolded-sighted > congenitally blind > late-onset blind; specifically 89.47% vs 83.34%, vs 71.43%, respectively (Figure 3B).

### 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 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 curved over sharp, and for a symmetric over asymmetric tactile 3D shapes.

### 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).

#### 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 group. As in Experiment1, individuals having cognitive impairment, neuropathy of the hands or fingers and hearing loss were not included in this experiment.

#### 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°, 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.

## fMRI design and procedure

Two experimental conditions were run. In **Condition 1** a battery of 6 sharp and 6 rounded 3D tactile stimuli was used, while in **Condition 2** - 6 symmetric and asymmetric stimuli were 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 5). Two questions were asked using a double 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 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, the participant 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)

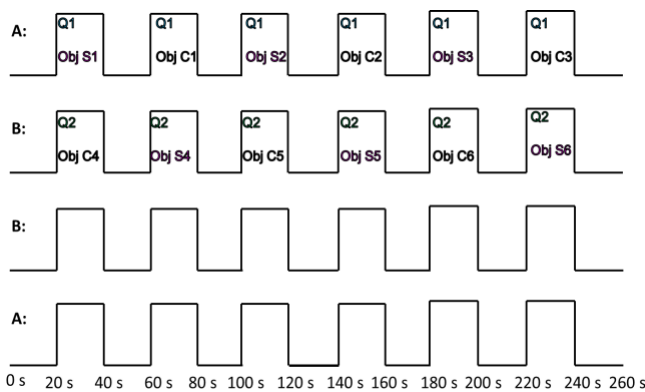
### Condition 2

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 the "A"-scans the participants were asked "Is the shape pleasing?" (scans type 1A) as each task-period of the scan. In the "B"-trials, the question was "Is the shape sharp?" (scans type 1B). After haptically exploring and evaluating the respective shape for 20 s, the participant answered by pressing either the left ("Yes") or the right ("No") button on the Response Box.



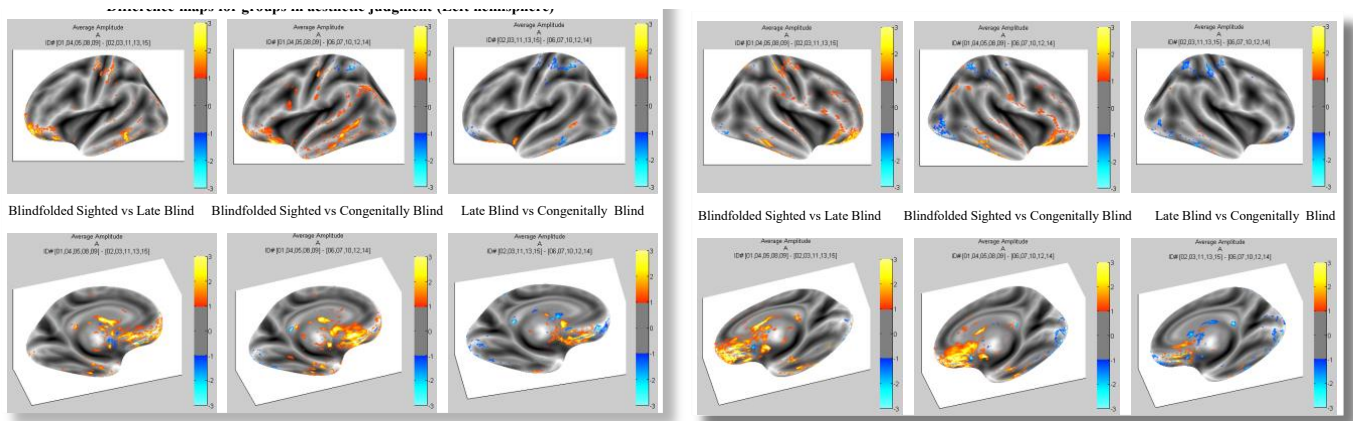
**Figure 7.** Examples of symmetric and asymmetric unfamiliar 3D stimuli, placed into our MRI-compatible multi-compartment box. Similarly to Condition 1 above, in the "A"-scans the participants were asked "Is the shape pleasing?" (scans type 2A) as each task-period of the scan. In the "B"-trials, however, the question was "Is the shape symmetric?" (scans type 2B). After haptically exploring and evaluating the respective shape for 20 s, the participant answered by pressing either the left ("Yes") or the right ("No") button on the Response Box.

## 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 comparison of the brain network for aesthetic judgment. The surface averaged activation maps in Figure 8 represents the differences between each two of the three groups of participants: 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 anteroventral cortex adjacent to the hypothalamus and dorsomedial thalamic nucleus and the nucleus accumbens, together with the ventro-medial pre-frontal and the orbitofrontal cortex.





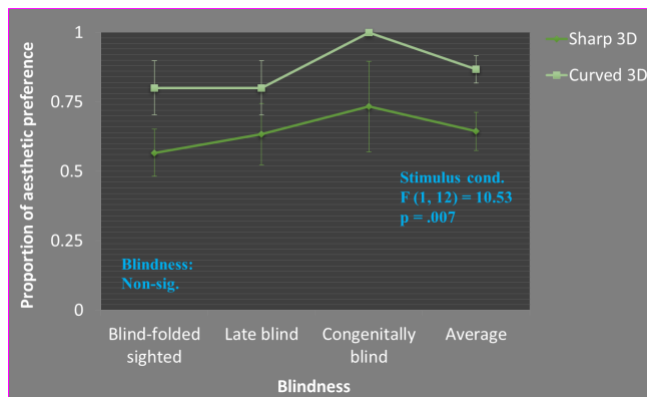
**Figure 8.** Difference maps of brain activation during aesthetic appreciation for three groups. **Left panel.** Lateral view (upper panel) and medial view (lower panel) of the left hemisphere. **Right panel.** Lateral view (upper panel) and medial view (lower panel) of the right hemisphere. The brain 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.

There is also a region of consistent activation in the middle temporal gyrus, typically involved in object processing. There were both a large overlap and significant characteristic differences across groups of different level of visual experience, and respectively – different level of development of the visual system. The detailed analysis of these data, however, is beyond the scope of this overview, but we want to note that the activation in these regions exhibits a gradient from being the strongest in blindfolded-sighted group to being the weakest in the congenitally blind group, although there are some brain regions that are more activated in the congenitally blind than the late-onset blind group, such as the *anterior cingulate cortex*.

## Concurrent behavioral results

### Aesthetic appreciation

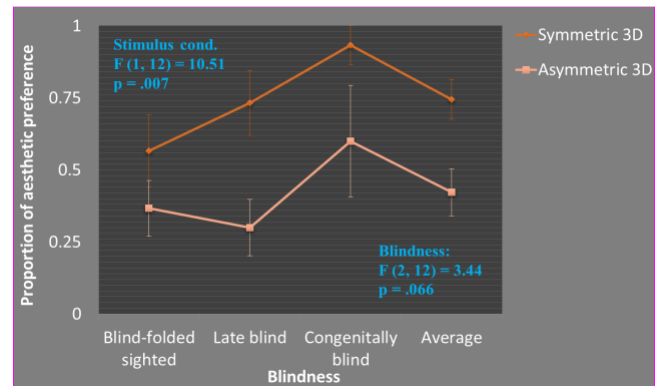
Analysis of the behavioral data (button-press responses to the aesthetic appreciation question: Is this shape pleasing? in the scanner) by ANOVA support the findings of the large-scale behavioral study on a different population in Experiment 1.



**Figure 9.** Aesthetic preference in sharpness vs curvedness in three visual experience groups.

Because there was no significant effect of visual experience on

aesthetic appreciation, we collapsed the data across groups and found that irrespective of visual experience participants significantly more appreciated ( $F(1, 12) = 10.53, p = 0.007$ ) curved tactile stimuli as aesthetically more pleasant than sharp tactile stimuli (Figure 9). Similarly, participants significantly more appreciated ( $F(1, 12) = 10.51, p = 0.007$ ) symmetric tactile stimuli as aesthetically more pleasant than asymmetric tactile stimuli (Figure 10).

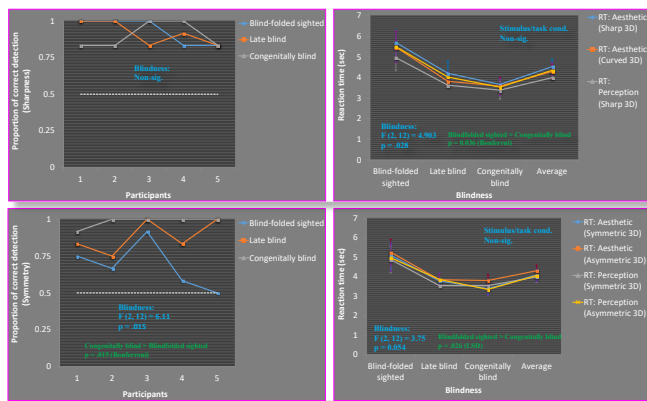


**Figure 10.** Aesthetic preference in symmetry vs asymmetry in three visual experience groups.

### Tactile discrimination

Analysis of sharpness and symmetry detection data in ANOVA further demonstrated that there was no significant effect of visual experience on sharpness detection, while there was a significant effect 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 was nonsignificant.



**Figure 11.** Correctness in sharpness and symmetry detection and reaction time (RT) taken in such detection and aesthetic appreciation in three visual experience groups.

To summarize, as compared to the sighted, blind people 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 or aesthetic bias for curved over sharp, and for a symmetric 3D tactile shape over asymmetric 3D tactile shapes. These first findings in the tactile modality are in line with prior findings in the visual modality which have shown that people prefer curved visual objects over sharp visual objects (Gómez-Puerto et al., 2015; Vartanian et al., 2013; Bar & Neta, 2006, 2007; Guthrie & Wiener, 1966; Silvia & Barona, 2009), and symmetric over asymmetric visual objects (Cárdenas & Harris, 2006; Little & Jones, 2003; Shepherd & Bar, 2011).

On average, there was no significant difference in stimulus preference or aesthetic appreciation between the blind and blindfolded sighted participants. However, we did observe that the proportion of individuals making a preference or aesthetic bias for a sharp or asymmetric 3D tactile shape were typically greater in the blind than in the sighted group. This possibly can have an ecological explanation, and be linked as well to the lack of visual experience

compensated by heightened tactile experience in the blind, which might lead to respective neural reorganization. However, due to unequal level of tactile experiences in everyday life, and always present individual differences, such a reorganization or remapping capacity should not be necessarily the same in all blind people. This may also indicate some form of top-down modulation of stimulus preference and aesthetic appreciation. We conclude that the lack of visual experience can impact to one or other degree how people perceive and appreciate 3D tactile structure. These findings are very informative and warrant further research on the underlying brain mechanisms or neural correlates of 3D tactile shape perception and aesthetic appreciation in the blind and visually impaired.

Interestingly, 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 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 or symmetric shapes. This difference is partly supported by the finding that sharp visual stimuli produce an increased activation of the amygdala as compared to the curved visual stimuli (Bar & Neta, 2007).

### fMRI Study: Experiment 2

Consistent with the results from 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 and for symmetric, than for sharp and for asymmetric tactile 3D shapes. However, this fact does not necessarily mean that there is no differences 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 recruit the somatosensory and motor areas of the brain, sighted people recruit more frontal whereas blind people – in particular, the congenitally blind – (paradoxically!) recruit more classically visual brain areas. Aesthetic appreciation requires involvement of higher order cognitive functions. Thus, the frontal areas, considered to be responsible for aesthetic judgment functions, were strongly activated during aesthetic appreciation in the blind-folded sighted individuals. Specifically, most of the *reward network* established in visual paradigms in the sighted, such as the ventro-medial prefrontal cortex (vmPFC), orbito-frontal cortex (OFC), most anterior cingulate (ACC), nucleus accumbens (Nacc) were either exclusively, or significantly more, activated in the *blind-folded* sighted than in any of the blind groups. In contrast, most visual *occipital* areas were engaged and most strongly activated in the *congenitally* blind. Here, we theorize that these results reflect deprivation-driven reorganization of the visual cortex to ‘serve’ the aesthetic judgement process. 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, to feed into the aesthetic judgement regions; or the visual cortex resources may be used in a higher-order manner.

The data also indicate that cortical functional reorganization in the blind, is a function of not only duration and level of visual deprivation but, especially, of the onset time of such deprivation, which reflects *the level of development of the visual system reached before* being deprived. Prior 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 blind or sighted participants show deactivation (Sadato et al., 2002) or less activation (Sadato et al., 1996; Wittenberg et al., 2004) of this region. Taken together, visual deprivation or absence of visual experience drive plastic reorganization. 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, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000) and other forms of tactile acuity tasks (Legge, Madison, Vaughn, Cheong, & Miller, 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 and 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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## References

Ackerley, R., Saar, K., McGlone, F. & Wasling, H. B. (2004). Quantifying the sensory and emotional perception of touch: differences between glabrous and hairy skin. *Frontiers in Behavioral Neuroscience*, 8.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, 17, 645-648.

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. *Neuropsychologia*, 45(10), 2191-2200.

Berlyne, D. E. (1971). *Aesthetics and psychobiology*. New York: Appleton-Century-Crofts.

Cacciamani, L. & Likova, L. T. (2017). Memory-guided drawing training increases Granger causal influences from the perirhinal cortex to V1 in the blind. *Neurobiology of Learning & Memory*, 141, 101-107. doi:10.1016/j.nlm.2017.03.013.

Carbon, C. C., & Jakesch, M. (2013). A model for haptic aesthetic processing and its implications for design. *Proceedings of the IEEE*, 101(9), 1-11. doi:10.1109/JPROC.2012.2219831.

Cárdenas, R. A., & Harris, L. J. (2006). Symmetrical decorations enhance the attractiveness of faces and abstract designs. *Evolution and Human Behavior*, 27(1), 1-18.

Cela-Conde, C. J., Marty, G., Maestu, F., Ortiz, T., Munar, E., Fernandez, A., Roca, M., Rosselló, J., & Quesney, F. (2004). Activation of the prefrontal cortex in the human visual aesthetic perception. *Proceedings of the National Academy of Sciences USA*, 101(16), 6321-6325.

Cohen, L. G., Weeks, R. A., Sadato, N., Celnik, P., Ishii, K., & Hallett, M. (1999). Period of susceptibility for cross-modal plasticity in the blind. *Ann. Neurol.*, 45, 451-460.

Craig, J. C. (1988). The role of experience in tactual pattern perception: A preliminary report. *International Journal of Rehabilitation Research* 11, 167-171.

Etzi, R., Spence, C., & Gallace, A. (2012). Aesthetic preferences for tridimensional shapes: A comparison between vision and touch. *Seeing and Perceiving*, 131.

Gallace, A. & Spence, C. (2011). Tactile aesthetics: towards a definition of its characteristics and neural correlates, *Social Semiotics*, 21:4, 569-589, DOI: 10.1080/10350330.2011.591998

Garner, W. R. & Clement, D. E. (1963). Goodness of pattern and pattern uncertainty. *Journal of Verbal Learning and Verbal Behavior*, 2, 446-52.

Kawabata, H., & Zeki, S. (2004). Neural correlates of beauty. *Journal of Neurophysiology*, 91, 1699-1705.

Goldreich, D., & Kanics, I. M. (2003). Tactile acuity is enhanced in blindness. *Journal of Neuroscience*, 23, 3439-3445.

Grant, A. C., Thiagarajah, M. C., & Sathian, K. (2000). Tactile perception in blind braille readers: A psychophysical study of acuity and hyperacuity using gratings and dot patterns. *Perception & Psychophysics*, 62, 301-312.

Gerardo Gómez-Puerto, Enric Munar, Marcos Nadal (2015). *Front Hum Neurosci*. 9: 712. Published online 2016 Jan 12. doi: 10.3389/fnhum.2015.00712 PMID: PMC4709714

Guest, S. Dessirier, J. M., Mehrabyan, A., McGlone, F., Essick, G., Gescheider, G., Fontana, A., Xiong, R., Ackerley, R., & Blot, K. (2011). The development and validation of sensory and emotional scales of touch perception. *Atten Percept Psychophys*, 73, 531-550.

Guthrie, G., & Wiener, M. (1966). Subliminal perception or perception of partial cue with pictorial stimuli. *Journal of Personality and Social Psychology*, 3(6), 619.

Heller, M. A. (1989b). Texture perception in sighted and blind observers. *Perception & Psychophys*, 45, 49-54.

Jakesch, M., & Carbon, C. C. (2012). The mere exposure effect in the domain of haptics. *PLoS ONE*, 7(2). doi:10.1371/journal.pone.0031215.

Jakesch, M., Zachhuber, M., Leder, H., Spingler, M., & Carbon, C. C. (2011). Scenario-based touching: On the influence of top-down processes on tactile and visual appreciation. *Research in Engineering Design*, 22, 143-152.



- Klatzky, R. L., Lederman, S. J., & Reed, C. (1989). Haptic integration of object properties: texture, hardness, and planar contour. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 45-57.
- Köhler, W (1929). *Gestalt Psychology*. New York: Liveright.
- Legge, G. E., Madison, C., Vaughn, B. N., Cheong, A. M., & Miller, J. C. (2008). Retention of high tactile acuity throughout the life span in blindness. *Perception & Psychophysics*, 70, 1471-1488.
- Legge, G. E., Madison, C., Vaughn, B. N., Cheong, A. M., & Miller, J. C. (2008). Retention of high tactile acuity throughout the life span in blindness. *Perception & Psychophysics*, 70, 1471-1488.
- Likova, LT (2017). Addressing long-standing controversies in conceptual knowledge representation in the temporal pole: A cross-modal paradigm. *Proceedings of Human Vision and Electronic Imaging*, pp. 268-272(5). doi: <https://doi.org/10.2352/ISSN.2470-1173.2017.14.HVEI-155>.
- Likova, LT (2018/*in press*). Brain reorganization in adulthood underlying a rapid switch in handedness induced by training in memory-guided drawing. In: *Neuroplasticity*. Ed. Chaban V. ISBN 978-953-51-5598-0.
- Likova, L. T. (2010). Drawing in the blind and the sighted as a probe of cortical reorganization. *IS&T/SPIE Electronic Imaging*, 752708–752720.
- Likova, L. T. (2012). Drawing enhances cross-modal memory plasticity in the human brain: a case study in a totally blind adult. *Frontiers in Hum. Neurosci.*, 6: 44. doi: 10.3389/fnhum.2012.00044.
- Likova, L. T. (2014). Learning-based cross-modal plasticity in the human brain: Insights from visual deprivation fMRI. In: *Advanced Brain Neuroimaging Topics in Health and Disease-Methods and Applications*, 327–358.
- Likova, L. T. (2015). Temporal evolution of brain reorganization under cross-modal training: insights into the functional architecture of encoding and retrieval networks. *IS&T/SPIE Electronic Imaging*, 9394: 17–32.
- Little, A. C. & Jones, B. C. (2003) Evidence against perceptual bias views for symmetry preferences in human faces. *Proceedings of the Royal Society of London B*, 270, 1759-1763.
- Martindale, C., Moore, K., & Borkum, J. (1990). Aesthetic preference: Anomalous findings for Berlyne's Psychobiological Theory. *The American Journal of Psychology*, 103(1), 53-80.
- Martindale, C., Moore, K., & West, A. (1988). Relationship of preference judgments to typicality, novelty, and mere exposure. *Empirical Studies of the Arts*, 6, 79-96.
- Montagu, A. (1971). *Touching: The Human Significance of the Skin*. New York: Columbia University Press.
- Munsinger, H., & Kessen, W. (1964). Uncertainty, structure, and preference. *Psychological Monographs: General and Applied*, 78(9), 1-24.
- Palmer, S. E., & Griscom, W. S. (2013). Accounting for taste: Individual differences in preference for harmony. *Psychonomic Bulletin and Review*, 20(3), 453-461.
- Palmer, S. E., Gardner, J. S., & Wickens, T. D. (2008). Aesthetic issues in spatial composition: Effects of position and direction on framing single objects. *Spatial Vision*, 21(3-5), 421-449.
- Pasqualotto, A., & Newell, F. N. (2007). The role of visual experience on the representation and updating of novel haptic scenes. *Brain and Cognition*. 65, 184-194.
- Pasqualotto, A., & Proulx, M. J. (2012). The role of visual experience for the neural basis of spatial cognition. *Neuroscience & Biobehavioral Reviews*, 36, 1179-1187.
- Proulx, M. J., Brown, D. J., Pasqualotto, A., & Meijer, P. (2014). Multisensory perceptual learning and sensory substitution. *Neuroscience & Biobehavioral Reviews*, 41C, 16-25.
- Rubin, J. A. (1976). The exploration of a tactile aesthetic. *New Outlook for the Blind*, 70, 369-375.
- Sadato, N., Okada, T., Honda, M., & Yonekura, Y. (2002). Critical period for cross-modal plasticity in blind humans: A functional MRI study. *NeuroImage*, 16(2), 389-400.
- Sadato, N., Pascual-Leone, A., Grafman, J., Ibanez, V., & Deiber, M. P., Dold, G., & Hallett, M. (1996). Activation of the primary visual cortex by Braille reading in blind subjects. *Nature*. 380, 526-528.
- Sathian, K., & Stilla, R. (2010). Cross-modal plasticity of tactile perception in blindness. *Restor. Neurol. Neurosci.*, 28(2): 271–281.
- Shepherd, K., & Bar, M. (2011). Preference for symmetry: Only on Mars? *Perception*, 40(10), 1254-1256.
- Silvia, P. J., & Barona, C. M. (2009). Do people prefer curved objects? Angularity, expertise, and aesthetic preference. *Empirical Studies of the Arts*, 27, 25-42.
- Tinio, P. P. L., & Leder, H. (2009). Just how stable are stable aesthetic features? Symmetry, complexity, and the jaws of massive familiarization. *Acta Psychologica*, 130(3), 241-250.
- Van Boven, R. W., Hamilton, R. H., Kauffman, T., Keenan, J. P., & Pascual-Leone, A. (2000). Tactile spatial resolution in blind Braille readers. *Neurology* 54, 2230-2236.
- Vartanian, O., & Goel, V. (2004). Neuroanatomical correlates of aesthetic preference for paintings. *NeuroReport*, 15(5), 893-897.
- Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L.B., Leder, H., Modroño, C., Nadal, M., Rostrup, N., Skov, M. (2013). Impact of contour on aesthetic judgments and approach-avoidance decisions in architecture. *Proceedings of the National Academy of Sciences*, 110 (Supplement 2) 10446-10453; DOI: 10.1073/pnas.1301227110
- Wittenberg, G. F., Werhahn, K. J., Wassermann, E. M., Herscovitch, P., & Cohen, L. G. (2004). Functional connectivity between somatosensory and visual cortex in early blind humans. *Eur. J. Neurosci*.