Title
An Exploratory Study on the Effect of Contour Types on Decision Making via Optic Brain Imaging Method (fNIRS)

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 45(45)

Authors
Tuna Demircioglu, Esin
Girişken, Yener
Çakar, Tuna, Çakar

Publication Date
2023

Peer reviewed

An Exploratory Study on the Effect of Contour Types on Decision Making via Optic Brain Imaging Method (fNIRS)

Esin Tuna Demircioglu, (esintuna1@gmail.com)
Department of Neuroscience, Yeditepe University, Istanbul, Turkey
Yener Girisken, (yener.girisken@thinkneuro.net)
Faculty of Economics and Administrative Sciences, Final International University Istanbul, Turkey
Tuna Cakar, (cakart@mef.edu.tr)
Department of Computer Engineering, MEF University, Istanbul Turkey

Abstract

Decision making is a combination of our positive anticipations from the future with the contribution of our past experiences, emotions and what we perceive at the moment. Therefore, the cues perceived from the environment play an important role in shaping the decisions. Contours, which are the hidden identity of the objects, are among these cues. Aesthetic evaluation, on the other hand, has been shown to have a profound impact on decision-making, both as a subjective experience of beauty and as having an evolutionary background. The aim of this empirical study is to explain the effect of contour types on preference decisions in the prefrontal cortex through risk-taking and aesthetic appraisal. The obtained findings indicated a relation between preference decision, contour type, and PFC subregion. The results of the current study suggest that contour type is an effective cue in decision-making, furthermore, left OFC and right dlPFC respond differently to contour types.

Keywords: Aesthetics; Decision-making; PFC; Contour; Risk.

Introduction

Decision-making is the judgment that emerges as a synthesis of many facts, such as past experiences and current emotions, that people make every day, consciously or unconsciously, in order to achieve the expected result. It has been shown that there are three main types of decision-making: memory-based, value-based, and free-choice. In memory-based decision-making, the individual must remember the decisive cues for optimum decision, while value-based decision-making is based on reward and choice history (Funahashi, 2017). Long-term memory retains how well the output matches the emotional and targeted output from past experiences. In particular, survival in the wild depends on the flexible evaluation of threatening stimuli by processing perceived information from the environment. The precipitating experiences are never the same, and fear-triggering cues from the past experience are used in future encounters that are sufficiently similar to the original event, thus the generalization is important as it affects current judgments. Hence, when similar cues are detected in future decisions and behaviors, the probability of the decision meeting the expectation is assured. (Asok, Kandel & Rayman, 2019; Lerner, et al., 2015). Another factor that determines whether the preference is positive, or negative is the effects of aesthetic judgments that play a significant role in our lives when evaluated as object appraisal. Positive aesthetic judgments of perceived morphological features in terms of mate selection are an indication that the mate has good genes, and then the offspring will have a high probability of having good genes. (Henshaw, Fromhage, & Jones, 2022; Scheib, Gangestad, & Thornhill, 1999). The preference tendency is usually shaped by coded cues as positive outcomes experienced by the person in the past. Therefore, while making a choice or decision, it is estimated that future benefits will be obtained due to the positive expectation for the decision to be taken in the current situation. In this context, the aesthetic perception regarding beauty, preference, and pleasantness as an integral part of our daily life choices also seem to help us keep our future anticipations away from uncertainty and in a positive field (Reber, Schwarz, & Winkielman, 2004; Ryan, 2021; Smith, 2005; Zaidel, 2015). Among the factors that allow us to perceive an object correctly are symmetry, prototypicality, contrast, complexity, and perceptual fluency. Furthermore, these factors affect the liking of visual objects (Reber et al., 2004). The more familiar these factors are, the more positive our attitude towards that object becomes (Westerman, Lanska, & Olds, 2015). In addition, contours are an important cue that helps us to estimate the potential shape of the objects we see around us by converting the two-dimensional state of the objects into three-dimensional ones in our minds (Corradi, & Munar, 2020). When sharp and curved contours are considered, people tend to choose objects and shapes with curved contours, since sharp contours trigger the amygdala and create an implicit threat effect (Bar, & Neta, 2007). In addition, a liking for objects with curved contours has been shown in non-Western cultures, infants, and great apes, and this curvature effect has been shown to be universal. Objects with curved contours were associated with more positive words and warmth, while sharp contours were associated with negative words and threats (Gómez-Puerto, Munar, Acedo, & Gomila, 2013; Jadva, Hines, & Golombok, 2010; Munar, Gómez-Puerto, Call, & Nadal 2015; Palumbo, Ruta, & Bertamini, 2015). While this pattern of preference basically has an evolutionary dimension as humans' instinct to avoid danger, it also seems to shape aesthetic perceptions for the same reason.

In light of all this information, the prefrontal cortex (PFC), which is the ultimate area of decision-making, plays an important role. The processing, interpretation, and generation of the emotional response are influenced by the extensive connections between the amygdala, and the PFC, particularly the ventromedial (vmPFC) (Gold, et al., 2016).

Moreover, the orbitofrontal cortex (OFC) and amygdala are thought to play a role in altering signal-outcome relationships (Morrison, et al., 2011). It has been observed that the declared intensity of the aesthetic experience is inversely correlated with the strength of the medial OFC (mOFC) activation (Ishizu, & Zeki, 2011). On the other hand, the distinctive activity of the left dorsolateral PFC (dlPFC) is associated with the aesthetic perception of beauty. In contrast, increased activity in the left dlPFC and decreased activity in the right dlPFC are associated with risk-taking in the context of loss, especially when it comes to protection (Huang et al., 2017). On the other hand, in a study in which left dlPFC activity was inhibited, increased activity of the right dlPFC was shown to increase risk preferences (Yang et al., 2017) This shows that the left dlPFC takes a more active role in utilitarian decisions (Zheng, Lu, & Huang, 2018).). However, the dlPFC has been shown to be essential for manipulating representations in working memory and reasoning, the left dlPFC for manipulating verbal and spatial information in working memory, and the right dlPFC for verbal and spatial reasoning (Barbey, Koenigs, & Grafman, 2013). Thus, the dlPFC has been shown to have executive functions in the decision-making process.

It is known that sharp contours create an implicit threat, and curved contours predominate in the trend of preference (Bar, & Neta, 2007; Bertamini et al., 2016; Gómez-Puerto, Munar, & Nadal, 2016). Therefore, presenting these two contour types to the participants, this study has been prepared in order to investigate whether the preferences in their most primitive form are affected more by threat perception or aesthetic perception, or whether they will appear as a combination of both preferences. The aim of the current empirical study is to investigate the functional relationships between PFC regions during preference decisions to reveal whether the contour type affects aesthetic and threat perception.

Method

Functional near-infrared spectroscopy (fNIRS) technique investigates hemodynamic changes in the cerebral cortex. The basic principle of the fNIRS technique is, light at wavelengths of 690-830 nm is sent to the cortex, this light is absorbed by the oxygenated and deoxygenated hemoglobin in the tissue, and some of it is scattered back. The returning signals, which provide functional contrast, are recorded with the detector (Fig1) (Ayaz et al., 2006; Karim, 2012; Peng, & Hou, 2021). In the current empirical study, the fNIRS technique was preferred because it provides a more comfortable environment for the participants due to its ease of use, and it provides the opportunity to easily record the hemodynamic changes in the PFC in the laboratory. The objective use of this technique was to perform a comprehensive study of the activations of the dlPFC, mPFC, and OFC in tasks. The images used in this study were conducted from the Bar & Neta Lab. These stimuli are objects used in daily life, containing the same semantic information and differing only by their sharp and curved contours, with a gray background and without any inherent positive or

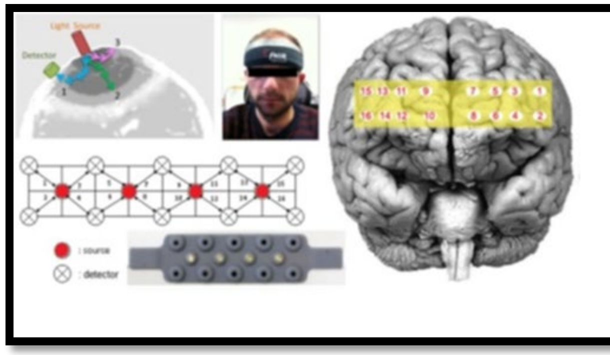

Figure 1: On the left, the working principle of fNIRS, its application to the participant, and the placement of the optode and detectors, on the right, the placement of the channels at the prefrontal area has shown (İşbilir, et al., 2019).

negative qualities (Fig2). In the survey, images with different contour types were shown in the same window and the participants were asked to choose which one they liked more. In the fNIRS experiment, these images were shown one by one, and then asked if they liked them. The purpose of this was to examine the activity changes in the PFC when the participants were examining and judging the contour types that have been shown by various studies to have different effects. In order to determine the general preference tendencies of the participants, a survey was conducted using pairs of images with sharp and curved contours in 250 subjects as a preliminary study.

Figure 2: Example of everyday object stimuli containing the same semantic information that differs only in contour type.

The most and the average liked curved and sharp objects were examined. Twenty-nine participants (female:18, age:20-42) were tested. All participants have no mental or visual impairment, they were also not related to art. The participants completed the tasks consisting of 60 images by showing the image screen of 5 seconds, the decision-making screen of 3 seconds, and the fixation screen of 8 seconds was given to reduce the hemodynamic changes to the baseline level (Fig3).

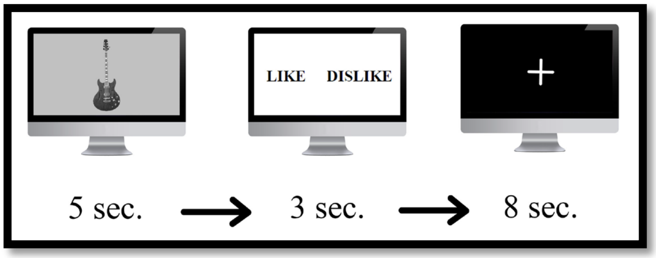

Figure 3: Task block of the fNIRS experiment for a stimulus.

The keys participants needed to press to indicate liking or dislike were randomly switched in each block to avoid lateralization biases. The obtained data were analyzed with repeated-measures ANOVA.

Results

In the current study, the relation between preference decisions, contour type, and PFC areas has been evaluated to clarify further understanding of aesthetic perception. The obtained data has been evaluated with a one-sided paired-sample t-test and, showed that there is a significant relation between contour types and PFC areas. Two strategies were used to analyze the data, first, the entire duration of the task that included a visual presentation and decision blocks, and second, the visual presentation and decision blocks were analyzed separately. Analysis of the entire task showed significant increases in activity in regions corresponding to channels at HbR1 ($p=0.008$), HbR3 ($p=0.07$), HbR15 ($p=0.057$), Oyx1 ($p=0.021$), and Oxy12 ($p=0.055$) in response to curved contoured objects. Analysis of the separate blocks showed increased activity in corresponding regions to channels at Oxy1 ($p=0.012$) for sharp contours, and at Oxy16 ($p=0.69$), HbR1 ($p=0.003$), HbR15 ($p=0.007$), and HbO13 ($p=0.019$) for curved contours in the decision block. The visual presentation block showed increased activity in corresponding regions to channels at hbr1 ($p=0.052$), HbR3 ($p=0.027$), and HbO ($p=0.082$) for curved contours. Furthermore, to assess the details of the relation between liking, contour type, and PFC areas repeated measures ANOVA was performed. According to deoxyhemoglobin (HbR) measurements ($F(3,81)=2.225$, $p=.092$, $\eta 2=.076$), there was a relation with liking, contour type, and PFC areas. In terms of hemodynamic changes that fNIRS record, the HbO signal increases, and the HbR signal decreases when a task is performed. Thus, HbO and HbR measurements are negatively correlated (Lee et al., 2018). In the 1-2 channels corresponding to the left dlPFC showed an increase in HbR means in dislike of sharp contours (M=.021; SE=.009), and a decrease in dislike of curved contours (M= -.005; SE=.012). In contrast, the HbR means of the 3-4 channels corresponding to the left dlPFC was slightly decreased in disliking curved contours (M=.006; SE=.012). Another interesting change in the dislike decision was recorded in channels 7-8 corresponding to the left OFC, where sharp contours (M=.017; SE=.010) showed an increase in HbR means and a salient decrease in decisions of curved contours (M= -.013; SE=.009). In the right PFC regions, a higher increase in dislike of sharp contours was recorded in channels 11-12 corresponding to the right mPFC regions, and in channels 15-16 corresponding to the right dlPFC region. In contrast, a slight increase in dislike of curved contours was recorded. In liking decisions, in 7-8 channels corresponding to the left OFC, a higher increase was recorded for curved contours (M=.016; SE=.010), while a milder increase was recorded for recorded contours (M= .007; SE=.009). The most dramatic difference, however, was in channels 15-16, corresponding to the of the right dlPFC, with a bold increase in the likes of curved contours (M=.035; SE=.012) and a slight increase in the likes of sharp contours (M=.006; SE=.016) (Fig 4).

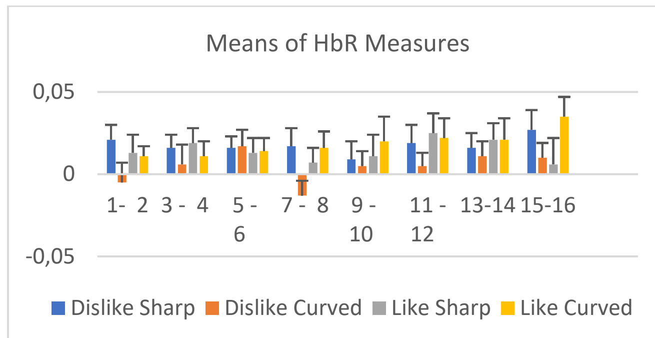

Figure 4: The figure presented herein displays the average HbR measurements, where comparisons were made between preference and contour types using Multivariate Tests.

Discussion

Decision-making is a complex cognitive process that involves the evaluation of various perceptual cues and associated reward values, resulting in the generation of judgments and the achievement of anticipated goals. Thus, the primary region involved in decision-making and executive control is the prefrontal cortex (Rouault, Drugowitsch, & Koechlin, 2019). In addition to these factors, incidental emotions also exert a significant influence on decision-making processes (Lerner, et al., 2015). Contour types, on the other hand, as low-level visual cues are an indispensable part of the object's identity. These types help individuals to evaluate the surroundings in a two-dimensional visual world by leading a conversion to a three-dimensional world in the brain (Corradi, & Munar, 2020). Accordingly, as mentioned before the sharp contours conveys an implicit threat, they shape the decisions. The decisions made in this study were primarily motivated by risk, as the employed stimuli elicited an implicit perception of threat. Hence, the preferences of the participants will be interpreted from two perspectives, namely aesthetic evaluation and risk evaluation. Moreover, the integration of these two dimensions is meaningful for a comprehensive understanding of the effect of contour types on the decision-making processes involved in the current study. Adhering to this perspective, analysis of the entire duration of the task indicated a significant decrease in activity at the left dlPFC specifically for curved contours than sharp contours. Whereas, the distinguishing of the task into the visual presentation and decision task indicates that increased activity at both left and right dlPFC was significant in the decision task whereas left dlPFC is significant in the visual presentation task for curved contours than sharp contours. It has been shown that the increased activity in the left vlPFC and dlPFC was linked to the moderating influence of cognitive reappraisal of incidental emotions on decision-making (Morawetz, 2019). While the arousal aspect of sensory stimuli is associated with the vmPFC, balancing the value of emotions is closely linked to the dlPFC (Nejati, 2021). With this respect, current results are in line with the empirical findings in accordance with that increased activity at the left dlPFC for the decision to dislike objects with curved contours. More specifically, the increased activity in the left dlPFC caused by the dislike of curved contours may be related to risk-taking behavior rather than aesthetic evaluation. This empirical finding is interesting for further studies, as the experience of beauty is associated with higher activity in the left dlPFC and negatively correlated with the finding that people tend to evaluate objects with curved contours as more aesthetically pleasing (Gómez-Puerto, Munar, & Nadal 2016, Cela-Conde 2004). On the other hand, the current findings are consistent with previous research that shows the involvement of the dlPFC in tasks that require active manipulation of visual stimuli (Barbey., Koenigs, & Grafman, 2013). Judgments made for sharp contours, on the other hand, cause decreased activity in the left dlPFC, which is a finding that can be evaluated in the future.

The OFC integrates sensory information from the amygdala to evaluate the expected value of an outcome and to determine its rewarding properties (Wallis, 2007). Furthermore, it has been shown that before a decision is made explicitly, OFC activity seems to influence it unconsciously (Soon, 2008). It has also been shown that the mOFC does not activate for ugliness, and may have an important role in monitoring the outcome of externally directed actions and modifying stimulus-reward relations (Ishizu, & Zeki, 2011; Walton, Devlin, & Rushworth, 2004). Therefore, it would be consistent to infer that ugliness has not had favorable outcomes in this region for aesthetic and objective experiences. The decreased activity in the left OFC observed in the disliking condition of sharp contoured objects, on the other hand, seems to be consistent with the finding that the ugliness causes the activity of the mOFC to decrease. However, the fact that dislike for objects with curved contours caused increased activity in the left OFC, which might indicate a possible conflict in monitoring stimulus-reward relationships. Nevertheless, liking sharp contoured objects resulted in a subtle increased activity at the left OFC. This may be due to personal experience with the beauty of such objects or the role of the OFC in monitoring stimulus-reward expectation and risk-taking behavior (Rolls, et al., 2022; Walton, et al., 2004). Since sharp contours are inherently perceived as a threat, the increased levels of neural activity in the left OFC suggest that aesthetic evaluation is not the only factor that influences decision-making in the context of the current design. Additively, disliking the curved contours caused increased levels of neural activity OFC, whereas decreased levels of neural activity in the liking decisions may be an important finding supporting the current suggestion. Disliking the curved contours caused increased levels of neural activity at 1-2 channels whereas decreased levels of neural activity at the 3-4 channels which both correspond to left dl PFC. In this case, the liking decisions of curved contours seem to reflect the judgment as to whether it is utilitarian to dislike rather than a positive aesthetic judgment.

The PFC forecasts the effects of one's own actions with guidance from the mPFC, particularly the vmPFC (Bechara, & Damasio, 2005). With this respect, the analysis of the separate blocks implies that there is a suggestive relation between decreased levels of neural activity in the right dlPFC for curved contours in the decision block. Additionally, liking sharp contoured objects led to a greater decreased level of neural activity at the right mPFC compared to disliking objects with curved contours. This suggests that disliking curved objects may be a conflict with survival instincts, leading to an evaluation of the emotional and personal consequences of this decision. Moreover, the activity of the mPFC for both like and dislike decisions suggests that it coincides with the finding that the mPFC is a causally relevant region for aesthetic appraisals (Ferrari et al., 2017). Liking objects with sharp contours resulted in lesser increased levels of neural activity in the right dlPFC compared to liking curved contours. This might be due to the right dlPFC being involved in maintaining alertness and visual reasoning, which may overlap with processing sharp contours (Barbey, et al., 2013; Mannarelli et al., 2015). Another interesting result of the current study was that the right dlPFC showed opposite activations in decisions to dislike sharp contours and to like curved contours. This change supports the empirical finding from the related literature that the increased activity of the right dlPFC significantly increases risk preference (Yang et al., 2017). Thus, the current empirical study is also appropriate for the interpretation that risk decisions may be associated with increased activity in the vmPFC and right dlPFC relative to aesthetic decisions.

In conclusion, considering that objects with different contour types are a sign of liking decisions, it seems that the decision-making of objects with sharp contours requires more processing in the PFC regions, unlike their curved counterparts. In particular, the variable activations of the left OFC and the right dlPFC in liking decisions emphasized that it is more important to measure the accuracy of the decision to be made. In addition, the fact that the participants like objects with curved contours, and that the aesthetic experience is positive, contributes to the idea that it has a role in eliminating the uncertainty for the future. In light of all these findings, the projections of preference decisions in the

PFC seem to be determined by what we dislike most rather than what we like best. The current data shows that there is a relationship between contour types and both aesthetic and threat perception thus on decision-making however, additional research is needed to gain a more comprehensive understanding of this observation.

Acknowledgments

This study was done as part of doctoral dissertation research named "Evaluation of Oblique Effect via Eye Tracking and fNIRS Techniques on Perceptual Fluency and Preference Behavior". This research is financially supported by a Private University research grant for the project no: AP-016.

References

Asok, A., Kandel, E. R., & Rayman, J. B. (2019). The Neurobiology of Fear Generalization. Frontiers in behavioral neuroscience, 12, 329. https://doi.org/10.3389/fnbeh.2018.00329

Ayaz, H., Izzetoglu, M., Platek, S. M., Bunce, S., Izzetoglu, K., Pourrezaei, K., & Onaral, B. (2006). Registering fNIR data to brain surface image using MRI templates. Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference, 2006, 2671–2674. https://doi.org/10.1109/IEMBS.2006.260835

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. Neuropsychologia, 45(10), 2191–2200. https://doi.org/10.1016/j.neuropsychologia.2007.03.008

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. Cortex; a journal devoted to the study of the nervous system and behavior, 49(5), 1195–1205. https://doi.org/10.1016/j.cortex.2012.05.022

Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. Games and Economic Behavior, 52(2), 336–372. https://doi.org/10.1016/j.geb.2004.06.010

Bertamini, M., Palumbo, L., Gheorghes, T. N., & Galatsidas, M. (2016). Do observers like curvature or do they dislike angularity?. British journal of psychology (London, England : 1953), 107(1), 154–178. https://doi.org/10.1111/bjop.12132

Cela-Conde, C. J., Marty, G., Maestú, F., Ortiz, T., Munar, E., Fernández, 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 of the United States of America, 101(16), 6321–6325. https://doi.org/10.1073/pnas.0401427101

Corradi, G., & Munar, E. (2020). The Curvature Effect. In M. Nadal & O. Vartanian (Eds.), The Oxford Handbook of Empirical Aesthetics (Vol. 34, Issue 1, pp. 35–52). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198824350.013.24

Ferrari, C., Nadal, M., Schiavi, S., Vecchi, T., Cela-Conde, C. J., & Cattaneo, Z. (2017). The dorsomedial prefrontal cortex mediates the interaction between moral and aesthetic valuation: a TMS study on the beauty-is-good stereotype. Social cognitive and affective neuroscience, 12(5), 707–717. https://doi.org/10.1093/scan/nsx002

Funahashi S. (2017). Prefrontal Contribution to Decision-Making under Free-Choice Conditions. Frontiers in neuroscience, 11, 431. https://doi.org/10.3389/fnins.2017.00431

Gold, A. L., Shechner, T., Farber, M. J., Spiro, C. N., Leibenluft, E., Pine, D. S., & Britton, J. C. (2016). Amygdala-Cortical Connectivity: Associations with Anxiety, Development, and Threat. Depression and anxiety, 33(10), 917–926. https://doi.org/10.1002/da.22470

Gómez-Puerto, G., Munar, E., & Nadal, M. (2016). Preference for Curvature: A Historical and Conceptual Framework. Frontiers in human neuroscience, 9, 712. https://doi.org/10.3389/fnhum.2015.00712

Gómez-Puerto, G., Munar, E., Acedo, C., and Gomila, A. (2013). "Is the human initial preference for rounded shapes universal? Preliminary results of an ongoing cross-cultural research" in 36th European Conference of Visual Perception 4, Bremen.

Henshaw, J. M., Fromhage, L., & Jones, A. G. (2022). The evolution of mating preferences for genetic attractiveness and quality in the presence of sensory bias. Proceedings of the National Academy of Sciences of the United States of America, 119(33), e2206262119. https://doi.org/10.1073/pnas.2206262119

Huang, D., Chen, S., Wang, S., Shi, J., Ye, H., Luo, J., & Zheng, H. (2017). Activation of the DLPFC Reveals an Asymmetric Effect in Risky Decision Making: Evidence from a tDCS Study. Frontiers in psychology, 8, 38. https://doi.org/10.3389/fpsyg.2017.00038

İşbilir, E., Çakır, M. P., Acartürk, C., & Tekerek, A. Ş. (2019). Towards a Multimodal Model of Cognitive Workload Through Synchronous Optical Brain Imaging and Eye Tracking Measures. *Frontiers in human neuroscience*, *13*, 375. https://doi.org/10.3389/fnhum.2019.00375

Ishizu, T., & Zeki, S. (2011). Toward a brain-based theory of beauty. PloS one, 6(7), e21852. https://doi.org/10.1371/journal.pone.0021852

Ishizu, T., & Zeki, S. (2011). Toward a brain-based theory of beauty. PloS one, 6(7), e21852. https://doi.org/10.1371/journal.pone.0021852

Jadva, V., Hines, M., & Golombok, S. (2010). Infants' preferences for toys, colors, and shapes: sex differences and similarities. Archives of sexual behavior, 39(6), 1261–1273. https://doi.org/10.1007/s10508-010-9618-z

Karim, H., Schmidt, B., Dart, D., Beluk, N., & Huppert, T. (2012). Functional near-infrared spectroscopy (fNIRS) of brain function during active balancing using a video game system. Gait & posture, 35(3), 367–372. https://doi.org/10.1016/j.gaitpost.2011.10.007

Lee, G., Jin, S. H., Yang, S. T., An. J., & Abibulaev, B. (2018). Cross-correlation between HbO and HbR as an effective feature of motion artifact in fNIRS signal. 6th International Conference on Brain-Computer Interface (BCI), Gangwon, Korea (South), pp. 1-3, doi: 10.1109/IWW-BCI.2018.8311513.

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. Annual review of psychology, 66, 799–823. https://doi.org/10.1146/annurev-psych-010213-115043

Mannarelli, D., Pauletti, C., Grippo, A., Amantini, A., Augugliaro, V., Currà, A., Missori, P., Locuratolo, N., De Lucia, M. C., Rinalduzzi, S., & Fattapposta, F. (2015). The Role of the Right Dorsolateral Prefrontal Cortex in Phasic Alertness: Evidence from a Contingent Negative Variation and Repetitive Transcranial Magnetic Stimulation Study. Neural plasticity, 2015, 410785. https://doi.org/10.1155/2015/410785

Morawetz, C., Mohr, P. N. C., Heekeren, H. R., & Bode, S. (2019). The effect of emotion regulation on risk-taking and decision-related activity in prefrontal cortex. Social cognitive and affective neuroscience, 14(10), 1109–1118. https://doi.org/10.1093/scan/nsz078

Morrison, S. E., Saez, A., Lau, B., & Salzman, C. D. (2011). Different time courses for learning-related changes in amygdala and orbitofrontal cortex. Neuron, 71(6), 1127–1140. https://doi.org/10.1016/j.neuron.2011.07.016

Munar, E., Gómez-Puerto, G., Call, J., & Nadal, M. (2015). Common Visual Preference for Curved Contours in Humans and Great Apes. PloS one, 10(11), e0141106. https://doi.org/10.1371/journal.pone.0141106

Nejati, V., Majdi, R., Salehinejad, M. A., & Nitsche, M. A. (2021). The role of dorsolateral and ventromedial prefrontal cortex in the processing of emotional dimensions. Scientific reports, 11(1), 1971. https://doi.org/10.1038/s41598-021-81454-7

Palumbo, L., Ruta, N., & Bertamini, M. (2015). Comparing Angular and Curved Shapes in Terms of Implicit Associations and Approach/Avoidance Responses. PloS one, 10(10), e0140043. https://doi.org/10.1371/journal.pone.0140043

Peng, C., & Hou, X. (2021). Applications of functional near-infrared spectroscopy (fNIRS) in neonates. Neuroscience research, 170, 18–23. https://doi.org/10.1016/j.neures.2020.11.003

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: is beauty in the perceiver's processing experience?. Personality and social psychology review : an official journal of the Society for Personality and Social Psychology, Inc, 8(4), 364–382. https://doi.org/10.1207/s15327957pspr0804_3

Rolls, E. T., Wan, Z., Cheng, W., & Feng, J. (2022). Risk-taking in humans and the medial orbitofrontal cortex reward system. NeuroImage, 249, 118893. https://doi.org/10.1016/j.neuroimage.2022.118893

Rouault, M., Drugowitsch, J., & Koechlin, E. (2019). Prefrontal mechanisms combining rewards and beliefs in human decision-making. Nature communications, 10(1), 301. https://doi.org/10.1038/s41467-018-08121-w

Ryan M. J. (2021). Darwin, sexual selection, and the brain. Proceedings of the National Academy of Sciences of the United States of America, 118(8), e2008194118. https://doi.org/10.1073/pnas.2008194118

Scheib, J. E., Gangestad, S. W., & Thornhill, R. (1999). Facial attractiveness, symmetry and cues of good genes. Proceedings. Biological sciences, 266(1431), 1913–1917. https://doi.org/10.1098/rspb.1999.0866

Smith C. U. (2005). Evolutionary neurobiology and aesthetics. Perspectives in biology and medicine, 48(1), 17–30. https://doi.org/10.1353/pbm.2005.0017

Soon, C. S., Brass, M., Heinze, H. J., & Haynes, J. D. (2008). Unconscious determinants of free decisions in the human brain. Nature neuroscience, 11(5), 543–545. https://doi.org/10.1038/nn.2112

Wallis J. D. (2007). Orbitofrontal cortex and its contribution to decision-making. Annual review of neuroscience, 30, 31–56. https://doi.org/10.1146/annurev.neuro.30.051606.094334

Walton, M. E., Devlin, J. T., & Rushworth, M. F. (2004). Interactions between decision making and performance monitoring within prefrontal cortex. Nature neuroscience, 7(11), 1259–1265. https://doi.org/10.1038/nn1339

Westerman, D. L., Lanska, M., & Olds, J. M. (2015). The effect of processing fluency on impressions of familiarity and liking. Journal of experimental psychology. Learning, memory, and cognition, 41(2), 426–438. https://doi.org/10.1037/a0038356

Yang, X., Gao, M., Shi, J., Ye, H., & Chen, S. (2017). Modulating the Activity of the DLPFC and OFC Has Distinct Effects on Risk and Ambiguity Decision-Making: A tDCS Study. Frontiers in psychology, 8, 1417. https://doi.org/10.3389/fpsyg.2017.01417

Yang, X., Gao, M., Shi, J., Ye, H., & Chen, S. (2017). Modulating the Activity of the DLPFC and OFC Has Distinct Effects on Risk and Ambiguity Decision-Making: A tDCS Study. Frontiers in psychology, 8, 1417. https://doi.org/10.3389/fpsyg.2017.01417

Zaidel D. W. (2015). Neuroesthetics is Not Just about Art. Frontiers in human neuroscience, 9, 80. https://doi.org/10.3389/fnhum.2015.00080

Zheng, H., Lu, X., & Huang, D. (2018). tDCS Over DLPFC Leads to Less Utilitarian Response in Moral-Personal Judgment. Frontiers in neuroscience, 12, 193. https://doi.org/10.3389/fnins.2018.00193