Distinct brain activities in response to ordered versus disordered stimulus Vanessa Ma, Jiaxu Han

Introduction

With the growth of social media, the scientific and professional communities have newly had greater access to even the minute preferences of average individuals. This has opened up vast fields and possibilities for research, from the eye-gaze and A/B tests in visual UX design to the use of NLP and other sentiment analysis on tweets, slogans, and other verbal content.

One such phenomenon we capitalized on is the rise of videos and media lamenting disorder and praising order. The rise of threads on widely perused channels such as Facebook's <u>Oddly Satisfying</u>, Reddit's <u>Oddly Unsatisfying</u> and <u>Maybe Maybe</u> <u>Maybe</u>, Instagram's <u>Mildly Infuriating</u> attest to human's general preference for 'order' defined on nebulous and far-reaching terms - patterns, symmetry, smoothness, alignment are easily accessible conjurations, but insofar as 'disorder' encompasses many more obscure ideas of what 'isn't right' - lopsided produce, sandwiches the wrong side up, forks without tines, knives swimming in gravy - the scope of what order encompasses must, therefore, be implicitly expanded beyond the low-hanging fruit.

The existing literature has made strides towards understanding the neural preference for order through two parallel channels. The first is understanding brain activity associated with the representation of stimuli with order-related features such as symmetry and textures. EEG experiments revealed a negatively associated Sustained Posterior Negativity (SPN) signal with symmetry when participants were given graphic patterns to rate as beautiful or not on a binary scale (Johnson & Hofel, 2003). A variety of neuro-physical experiments have been conducted on macaques, cats, and mice with carefully crafted textural stimuli by controlling the frequency of gratings on a plastic drum to understand the neural coding for texture, showing that the type I slowly adapting afferents converging onto the secondary somatosensory cortex are key to encoding roughness (Hsiao et al, 1993). but limited research has tried to bridge the arguably subconscious encoding of roughness with psychological preferences for smoothness. The main drawback of these studies stems from the assumption that neural processing for artificially controlled stimuli can be treated as a base for understanding brain activity in processing natural images.

The second is through attaining an abstract, neural correlate-level of behavioural preference. The earliest studies in this area sought to understand preference via the encoding of reward, which primarily engages the orbitofrontal cortex. Macaques with

lesions in the area show a lower performance in bandit tasks where arms are associated with rewards, and further electrophysics recordings showed that medial and lateral orbitofrontal cortex were closely related in self-driven and cued reward tasks respectively. (Walton et al, 2010; Saleem et al, 2008; Noonan et al, 2010; Bouret & Richmond, 2010). In some fMRI experiments, the amygdala was also cited as a conjunction in encoding reward representation, as it exhibits similar patterns of elevated activity as the orbitofrontal cortex during appetitive olfactory stimulus (Gottfried et al, 2020).

In particular, the fields of psychology, and even sometimes economics have dabbled in charting the neural mapping of preferences on a more abstract, aesthetic level. Often, subjects are asked to either rate or determine on a dichotomous - beautiful/not beautiful - scale. The prefrontal cortex and front-of-brain are generally agreed to be a main neural correlate for assessing beauty of paintings and natural scenes (Kawabata & Zeki, 2004; Cela-Conde et al, 2004). However, representations of order and preference do not necessarily seem to be cortical - the brainstem has also been implicated in the perception of musical consonance and dissonance, and responses are correlated directly to the level of perceived consonance, suggesting preference-encoding even in early, pre-attentive processing (Bidelman & Krishnan, 2009). The main drawback of these studies is their need for subjects to make a conscious value judgment after each stimulus presentation, which assumes that neural activity for conscious and subconscious decision-making is synonymous.

One last relevant aspect of the existing literature that cannot be ignored is clinical studies to understand the neural underpinnings of Obsessive Compulsive Disorder, defined as a mental disorder where a patient feels the overwhelming need to perform a certain routine or revisit certain thoughts repeatedly. While it does not directly map to a preference for order, the disorder often does manifest itself as such a preference - repetitive accusatory thoughts of disease may lead to a belief that being immensely clean would assuage such thoughts, for example. Hence, patients of this disorder are often found to exhibit behaviours like compulsive ordering and arranging, and a preoccupation with symmetry, easily likened to a heightened preference for order (Radomsky & Rachman, 2004). OCD patients were found to have cerebral metabolic differences compared to neurotypical persons: hypermetabolic responses were found in orbitofrontal cortex, as well as basal ganglia areas with particular emphasis on the putamen. Hence, it is possible that these are the neural correlates for signalling for the perception of order. On the other hand, hypometabolic responses were found in the inferior parietal and parieto-occipital junction (Kwon et al, 2003).

In light of the above literature, our main hypothesis is that perception of order and disorder are mostly likely to engage a combination of front-of-brain structures, in particular the orbitofrontal cortex. We secondarily hypothesize that brainstem and basal ganglia areas may reflect greater activity in the perception of order over disorder.

Methods

Subject

A 27-year-old healthy male volunteered to participate in the current experiment. Written informed consent was obtained before the scanning procedure. The subject expressed a preference for order and reported no personal history of any psychiatric disorders and no significant head trauma history.

Imaging Data Acquisition and Preprocessing

Imaging was performed at the University of Chicago MRI Research Center with a 3-T, whole-body MRI system (Phillips). The subject underwent two runs of an 8-min 26-second fMRI scan in the scanner with closely aligned acquisition parameters (TR=2000 ms; TE=25 ms; dimension=64x64x34). To allow for scanner stabilization, the initial 4 scans were discarded. In each remaining image volume, 34 axial slices were acquired using an interleaved ascending scanning sequence. The subject was instructed to stay awake and freely peruse the pictures but remain still. The preprocessing, as well as the following data analysis, was carried out using the SPM 12 toolbox (Ashburner et al., 2014). After preprocessing, the time series were aligned, slice-time corrected, normalized to MNI space, and smoothed at 8mm, with 2x2x2 mm resampled voxel size.

Stimulus Design

A full run of the stimuli lasted 8 minutes, using 20-second block design of disorder followed by order. Thus, the entire run consisted of 24 blocks, or 12 pairs of disorder vs. order conditions. Each pair of images conformed to a certain theme: Pies, Cakes, Manholes (White Paint), Manholes (Yellow Paint), Parking (Eye Level), Parking (Aerial), Toilets, Grooming, Tiles / Patterns (x2), Cluster, Miscellaneous (Daily Life) (Figure 1). Images were sourced from sites such as Reddit, Instagram, Buzzfeed and other related pop culture articles, and then supplemented by Google Images. In order to maintain some level of resolution to enable object identification by the subject, images were at least 900 x 900 pixels.

Data Analysis

Since a two-block design (order vs. disorder) was used for the experiment, we adopted a general linear model for the data analysis. More specifically, we tested (a)

which voxels respond more to the ordered stimuli than to the disordered stimuli across the two runs? (b) which voxels respond more to the disordered stimuli than to the ordered stimuli across the two runs? An example of a design matrix was presented in Figure 2.

Results

Compared to the disorder blocks, many voxels from both sides of the nucleus accumbens were more activated in response to the ordered stimulus (see Figure 3). Besides, some voxels in the cerebral white matter, posterior orbital gyrus, SCA subcallosal area, and right caudate also showed increased activity.

A wider range of brain regions demonstrated heightened activity in response to the disordered stimulus (see Figure 4). The highest activity appeared in the supplementary motor cortex area. Besides, occipital fusiform gyrus, thalamus, putamen, insula, posterior cingulate gyrus, fusiform gyrus, etc. also demonstrated significantly increased activity. The specific statistics for peak voxels for both contrasts can be found in Table 1. Since the disorder-order contrasts have many significant voxels, Table 1 only presents example peak voxels that locate in various brain regions.

Discussion

The current study aimed to investigate brain activity in response to disordered and ordered stimuli. Using a two-block design, one subject underwent a functional neuroimaging scan while viewing the stimulus. The data analysis found distinct brain patterns when viewing ordered versus disordered pictures. Such differences are not only manifested in the specific regions of activity but also the extent of the response. When viewing ordered pictures, a relatively localized cluster including part of the nucleus accumbens demonstrated increased activity compared to viewing disorder blocks. On the other hand, a significantly larger amount of brain areas showed increased activity in response to the disorder.

Nucleus accumbens is associated with a broad brain functions including reward learning (Day, 2007), motivation (Salamone, 2007), and drug addiction (Knutson, 2001). To our best knowledge, no research directly linked the function of the nucleus accumbens to the perception of order or disorder. On the other hand, clinical research suggested that patients with obsessive-compulsive disorder have dysfunctional reward circuitry which is characterized by attenuated activity in the nucleus accumbens compared to healthy people (Figee, 2011). Studies have also shown that deep brain stimulation of the nucleus accumbens can help decrease the depression and anxiety symptoms for treatment-resistant OCD patients (Denys, 2010; Huff, 2010; Sturm, 2003). The other question was why there were extensive brain areas responding to the disordered stimuli? One of our hypotheses was that disorderedness might take more cognitive resources to process all details of the information. One study showed that the amount of attention modulation required is positively correlated with the competition (i.e. disorderedness) of the stimuli when subjects were asked to group them (Mcmains, 2011). This result appears to be consistent with the common experience of having difficulty concentrating and processing information when living in a cluttered environment.

Limitations and Further Research

A few limitations of this study must be noted. Firstly, due to the small sample size, person-to-person variations, such as degrees of Obsessive Compulsive Disorder (OCD), idiosyncratic preferences could have played into these results. Secondly, the stimuli was non-normalized in many respects, including size and color - some images were squares, some were more vibrant than others, and the lack of color and size correction could have contributed to varying activity in the occipital cortex, as a direct subtraction between order and disorder sections (and vice versa) was not possible. Moreover, naturalized images necessarily contain noise, and specific 'elements' that cause the perception of disorder consequently cannot be isolated. However, it is important to note that realistic-ness of the stimuli is a necessary tradeoff with the ability to rigorously parametrize the stimuli.

Thirdly, there are some errors in experimental logistics, resulting in artifacts in the imaging scans. Artifacts might come from two sources. First, the beginning of the scan and the video were not completely in sync. Therefore, manually calculating the beginning of each block for each session might introduce some errors in the data analysis process. In addition, the video started too early and data for the first 8 seconds of the video from the first session were discarded due to scanner stabilization. Second, during the preprocessing, we found that the motion exceeded 3 mm (See Appendix Figure A). Though preprocessing steps helped reduce some of the noise, there were still artifacts in the final result that might directly related to motion. Using softwares like E-prime that can in sync with the scan and helping subjects reduce movements for fMRI scan might help improve the overall quality of the fMRI data.

Moving forward, possible areas of research include firstly homing in on sub-populations of interest, such as patients of OCD. For example, do degrees of severity on OCD assessment scales such as Y-BOCS, NIMH-GOCS correlate with elevated activation of the nucleus accumbens when viewing ordered stimuli? Or is activity a binary variable - either elevated or baseline? Secondarily, given the nebulous nature of the term 'order' and the subjective perception of order as addressed in the design of this study, the acquisition of the values that make up an individual's perception of order poses many interesting questions: given examples of parking, abstract art, food items etc, where the understanding of 'order' is not necessarily innate or universal, how does the brain signal change accordingly with acquisition and accommodation? Is accommodation of new 'order' variables simply an elevation of the baseline firing rate?

Lastly, fitting neural and voxel response models to natural images has been a hot topic of research in many aspects of neuroscience, and is no different here. Insight into what makes order-oriented neurons 'tick', if such neurons even exist in the nucleus accumbens, could yield immense insight into possible treatment for OCD patients.

Tables and Figures

Pizza

Tiles



(Aerial)

Tiles (2)





(Yellow Paint)



Parking (Eye View)





Manholes (White)

Toilets



Grooming



Daily Life

Figure 1a. Disorder Stimulus Design Examples

Cluster



Pizza



Parking (Eye View)



Cakes



Manholes (White)



(Yellow Paint)





Grooming









Tiles

Tiles (2)

Cluster

Toilets

Daily Life

Figure 1b. Order Stimulus Design Examples



Figure 2. An Example of Design Matrix



Figure 3. Voxels showed higher activity in response to ordered stimuli



Figure 4. Voxels showed higher activity in response to disordered stimuli

Table 1.

Statistics of the significant example voxels for both contrasts

Peak Voxel (x, y, z)	Location	pFWE
	<u> Contrast: Order - Disorder</u>	
17 14 -19	Nucleus accumbens	0.000
	<u> Contrast: Disorder - Order</u>	
0, -10, 53	Left supplementary motor cortex	0.000
-42, -2, 4	Left anterior insula	0.000
-19, -2, 0	Left pallidum	0.000
27, 0, 3	Right putamen	0.000

2, -16, 9	Right thalamus	0.000

Note. This is not an exhaustive list of all the significant clusters/voxels but to show example peak voxels that were scattered in the brain, especially for the disorder-order contrast.

Appendix



Figure A. Time series of motion

References

Ashburner, J., Barnes, G., Chen, C., Daunizeau, J., Flandin, G., Friston, K., ... & Penny, W. (2014). SPM12 manual. *Wellcome Trust Centre for Neuroimaging, London, UK*, 2464.

Bidelman, G. M., and A. Krishnan. "Neural Correlates of Consonance, Dissonance, and the Hierarchy of Musical Pitch in the Human Brainstem." Journal of Neuroscience, vol. 29, no. 42, 2009, pp. 13165–13171., doi:10.1523/jneurosci.3900-09.2009.

Bouret, S., and B. J. Richmond. "Ventromedial and Orbital Prefrontal Neurons Differentially Encode Internally and Externally Driven Motivational Values in Monkeys." Journal of Neuroscience, vol. 30, no. 25, 2010, pp. 8591–8601., doi:10.1523/jneurosci.0049-10.2010.

Cela-Conde, C. J., et al. "Activation of the Prefrontal Cortex in the Human Visual Aesthetic Perception." Proceedings of the National Academy of Sciences, vol. 101, no. 16, Dec. 2004, pp. 6321–6325., doi:10.1073/pnas.0401427101.

Cornish, Jennifer L., and Peter W. Kalivas. "Glutamate transmission in the nucleus accumbens mediates relapse in cocaine addiction." *Journal of neuroscience* 20.15 (2000): RC89-RC89. Figee, Martijn, et al. "Dysfunctional reward circuitry in obsessive-compulsive disorder." *Biological psychiatry* 69.9 (2011): 867-874.

Day, Jeremy J., and Regina M. Carelli. "The nucleus accumbens and Pavlovian reward learning." *The Neuroscientist* 13.2 (2007): 148-159.

Denys, Damiaan, et al. "Deep brain stimulation of the nucleus accumbens for treatment-refractory obsessive-compulsive disorder." *Archives of general psychiatry* 67.10 (2010): 1061-1068.

Salamone, John D., et al. "Effort-related functions of nucleus accumbens dopamine and associated forebrain circuits." *Psychopharmacology* 191.3 (2007): 461-482.

Gottfried, J. A. "Encoding Predictive Reward Value in Human Amygdala and Orbitofrontal Cortex." Science, vol. 301, no. 5636, 2003, pp. 1104–1107., doi:10.1126/science.1087919.

Huff, Wolfgang, et al. "Unilateral deep brain stimulation of the nucleus accumbens in patients with treatment-resistant obsessive-compulsive disorder: Outcomes after one year." *Clinical neurology and neurosurgery* 112.2 (2010): 137-143.

Jacobsen, Thomas, and Lea Höfel. "Descriptive and Evaluative Judgment Processes: Behavioral and Electrophysiological Indices of Processing Symmetry and Aesthetics." Cognitive, Affective, & Behavioral Neuroscience, vol. 3, no. 4, 2003, pp. 289–299., doi:10.3758/cabn.3.4.289. Kawabata, Hideaki, and Semir Zeki. "Neural Correlates of Beauty." Journal of Neurophysiology, vol. 91, no. 4, 2004, pp. 1699–1705., doi:10.1152/jn.00696.2003.

Kwon, Jun Soo, et al. "Neural Correlates of Clinical Symptoms and Cognitive Dysfunctions in Obsessive–Compulsive Disorder." Psychiatry Research: Neuroimaging, vol. 122, no. 1, 2003, pp. 37–47., doi:10.1016/s0925-4927(02)00104-x.

McMains, Stephanie, and Sabine Kastner. "Interactions of top-down and bottom-up mechanisms in human visual cortex." *Journal of Neuroscience* 31.2 (2011): 587-597.

Noonan, M. P., et al. "Separate Value Comparison and Learning Mechanisms in Macaque Medial and Lateral Orbitofrontal Cortex." Proceedings of the National Academy of Sciences, vol. 107, no. 47, Aug. 2010, pp. 20547–20552., doi:10.1073/pnas.1012246107.

Radomsky, A.s, and S Rachman. "Symmetry, Ordering and Arranging Compulsive Behaviour." Behaviour Research and Therapy, vol. 42, no. 8, 2004, pp. 893–913., doi:10.1016/j.brat.2003.07.001.

Rauch, Scott L., et al. "Neural Correlates of Factor-Analyzed OCD Symptom Dimensions: A PET Study." CNS Spectrums, vol. 3, no. 7, 1998, pp. 37–43., doi:10.1017/s1092852900006167.

Rudebeck, Peter H., and Elisabeth A. Murray. "Balkanizing the Primate Orbitofrontal Cortex: Distinct Subregions for Comparing and Contrasting Values." Annals of the New York Academy of Sciences, vol. 1239, no. 1, 2011, pp. 1–13., doi:10.1111/j.1749-6632.2011.06267.x.

Saleem, Kadharbatcha S., et al. "Complementary Circuits Connecting the Orbital and Medial Prefrontal Networks with the Temporal, Insular, and Opercular Cortex in the Macaque Monkey." The Journal of Comparative Neurology, vol. 506, no. 4, 2007, pp. 659–693., doi:10.1002/cne.21577.

Sturm, Volker, et al. "The nucleus accumbens: a target for deep brain stimulation in obsessive–compulsive-and anxiety-disorders." *Journal of chemical neuroanatomy* 26.4 (2003): 293-299.

Walton, Mark E., et al. "Separable Learning Systems in the Macaque Brain and the Role of Orbitofrontal Cortex in Contingent Learning." Neuron, vol. 65, no. 6, 2010, pp. 927–939., doi:10.1016/j.neuron.2010.02.027.