Perceptual interactions in depth perception: A quantitative EEG study

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Abstract

Percepts of different sensory modalities have been shown to interact with one another. Previous studies have qualitatively looked into the results of the interactions between stereo depth and specific pictorial depth cues, but failed to address the interaction themselves. My study will quantitatively investigate perceptual interactions between pictorial (two dimensional) and stereo (three dimensional) depth perception, the combination of which I term combined depth perception. Using a steady-state visually evoked potential (SSVEP) paradigm and a high density EEG net, the neural activity of eight subjects was recorded during the alternation and detection of different types of depth. I proposed and implemented the Relative Peak Strength variable, in order to quantitatively compare and plot the response strengths of each electrode. The perception of pictorial depth was observed to induce neural activity in the ventral stream, while stereo depth was observed to induce activity in the dorsal stream, suggesting these percepts have different functions when perceiving depth. The perception of combined depth behaves like a Gestalt, in which pictorial depth and stereo depth are not processed parallel to each other. Furthermore, this study suggests that stereo depth is the predominant type of depth perceived in combined depth with pictorial depth sometimes acting as a supplement depending on task. This connection between depth percepts and streams should be further investigated, as it could lead to a better understanding of the perceptual mechanisms underlying the reconstruction of the visual world.

Personal Section

I have always been mesmerized by the concept of Virtual Reality (VR), especially in science fiction - ranging from books such as *Ready Player One*, to movies like *The Matrix*. One common assumption in all these works is that VR technology would be more realistic and hence more immersive in the future. Being a VR fanatic, I became obsessed with a science fiction series called ‘Sword Art Online’ (SAO). This series is about a Virtual Reality online game in which players immerse their consciousness into the game by using something called a ‘NERvGEAR’. As the story goes, the developer removed the logout button and locked everyone inside, where the ‘NERvGEAR’ would kill users when they died in the game. The game then became one of survival. In my opinion this series most accurately depicts the possibilities and possible dangers of future VR technology as it gets more realistic. (You should definitely give it a read!)

SAO inspired me to study VR technology. Sadly, I didn’t find any VR techniques that allow us to be fully immersed into an alternate reality, instead I found that current VR technology is merely a computer screen you wear on your head. My goal therefore was to improve current VR techniques, to make them more immersive and realistic. However, we cannot create a realistic world, if we do not know what makes it realistic. Hence, the first step towards achieving my goal was to look into what causes the verisimilitude in current VR technology. So, I began to do some research into current VR technology. In order to understand what gives this sense of realism, I proceeded to teach myself geometric optics in order to investigate the optics in a Google Cardboard – a cheap ‘VR’ display. I also dissected an ox eye in order to get a better grasp of the visual system, but nothing was found related to the sense of realness. After months of research on immersiveness, I stumbled upon the idea of depth perception, which I learned to be the source of ‘realness’ in VR and 3D movies. By further researching depth perception, I found an article by Dr. Vishwanath regarding a new hypothesis on stereo depth, or three dimensional depth, which made me curious about the current state of research on depth perception. I realized that there is much more to learn regarding depth perception, and there are gaps in the literature specifically on how depth percepts interact with each other. Therefore, I formulated my study at MIT with Dr. Sinha based on questions I had on depth perception, to both obtain a greater understanding of the topic and satisfy my curiosity.

As a high school student, I have always striven to tackle the most difficult and complicated problems. I thought that science research was all about solving major problems, problems that provide the most challenges and have the most impact on society, until I conducted this study. The first step of my study was to create the stimuli, which was more difficult than I expected. First, I had to plan out all conditions so that each stimulus could provide unique and useful information. After a few days of planning, I ultimately created 15 pictures that were paired up to create 9 conditions. But I was far from completion - I had to find the exact amount of binocular disparity in order to induce a precise amount of three dimensional depth on a 2D image, then adjusted the drop shadow and perspective in order to make the images as realistic as possible. After improving the realism of the stimuli, the next step was to remove confounding variables and strengthen the impression of depth. I did this by making the pictures grayscale and adding dots that strengthen the impression of stereo depth. Finally there were minor edits to maintain consistency, such as adjusting the size and positions of targets within the stimuli so that they would not introduce confounding aspects. This whole process took around two weeks, which was far beyond the couple of days I had expected. Through the process of stimuli creation, I learned that science can often be about solving small problems; and these minor problems can be just as challenging, impactful and meaningful as the major ones. Since each and every one of these seemingly small studies come together in the end, and they combine to create a whole that is greater than its parts – a Gestalt.

Research Section

Introduction

My study looked at neural activity during different types of visual depth perception in 8 subjects using an EEG, mainly focusing on how we perceive depth in real life. There are two different types of visual depth - pictorial depth (depth on a two-dimensional plane, induced by pictorial depth cues such as shading) and stereo depth (true three dimensional depth believed to be induced by binocular disparity). In real life, pictorial depth cues and binocular disparity are both present in our daily experiences, which leads to the simultaneous perception of stereo and pictorial depth. However, there is no term for this combined percept, so I will call it *combined depth perception*. There were studies that qualitatively investigated the combination of stereo depth and specific pictorial depth cues. They all show that the impression of depth was strengthened when both stereo and pictorial cues were present, however they failed to address the mechanisms behind the combination (Bulthoff & Mallot, 1988; Johnston, Cumming & Parker, 1993; Schiller, Slocum, Jao, & Weiner, 2011). In this study, I propose possible interactions between pictorial and stereo depth percepts based on two different theories: the structuralistic approach and the Gestalt approach.

Structuralist approach. The structural approach suggests that percepts are solely formed by combining sensations. For example, the concept of structuralism would suggest that the perception of images on a screen is due to the summation of individual pixels. Following this approach, combined depth would be perceived as the combination of stereo depth and pictorial depth. Hence neural activities during the perception of combined depth should correspond with neural activity during the perception of pictorial and stereo depth.

Gestalt theory. The Gestalt theory suggests that the brain organizes and analyzes sensory information to form a Gestalt, or a whole new percept (Koffka, 1935). This resulting Gestalt could be entirely different from the raw sensory information, as seen through the impression of a white triangle in Kanizsa's triangle (Figure 1). According to this theory, pictorial and stereo depth would combine to form a whole new percept which would behave differently from pictorial or stereo depth percepts, and hence induce different neural activities. This study would take a Gestalt approach to analyse the combined perception of depth. This would be achieved through the comparison of different neural activities in stereo, pictorial and combined depth perception.

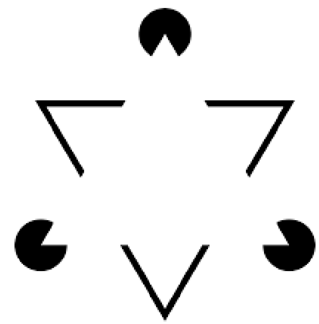

Figure 1. Kanizsa's Triangle as a demonstration of Gestalt.

EEG Paradigm

The Steady-State Visually Evoked Potential (SSVEP) paradigm was used in this study. An SSVEP paradigm involves presenting a flickering stimuli at a set frequency, then locating EEG electrodes which responded at this frequency. This paradigm is known to have a high signal-to-noise ratio amongst EEG paradigms (Norcia, Appelbaum, Ales, Cottereau & Rossion, 2015), which makes it suitable for this current study as a means to detect neural activities.

Stimuli

I designed and created nine pairs of stimuli using Adobe Photoshop CC 2017 and presented them on a 16x12in 2007FPb Dell monitor with 1600x1200px resolution and a refresh rate of 60Hz. All pairs flickered at a frequency of 2.4 Hz for 20 seconds using Psychtoolbox for MATLAB, with consideration of the latency of evoked responses to depth from prior research (Hou et al., 2006; Liu, 2013). A conventional flickering checkerboard that alters at the same frequency was used to detect the peak frequency (Norcia et al., 2015). The other eight stimuli were equally split into two groups of four – stimuli which involved *detecting* depth and stimuli with constantly *alternating* amounts of depth.

Stereoscopic stimuli. Stereoscopic stimuli in this study utilizes binocular disparity and red-green anaglyphs. All stimuli in this study are created in grayscale due to the usage of anaglyphs. Dots are also added to the stimuli to enhance disparity information. Since electronics would interfere with EEG acquisition, this technique is optimal as it can induce binocular disparity without using electronics such as head mounted displays.

Using my knowledge of geometry and optics, I developed a formula (see Equation 1) to calculate the distance between left and right images in order to produce a stereoscopic stimulus (Figure 2):

$$S = \frac{|D_2|}{D_1 + D_2} \times IPD \qquad (1)$$

The direction the left and right images have to shift is dependent on whether the apparent image is in front of or behind the screen. If the image is behind the screen, the red image is shifted towards the right and the green image is shifted to the left by S/2, and vice versa. In my experiment, the viewing distance (D_1) would be 60cm, the distance from stimulus to screen (D_2) was

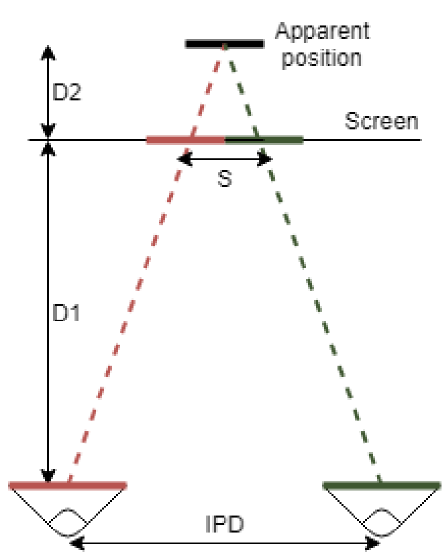

Figure 2. Geometry of stereoscopic viewing through anaglyphs. Assume an observer with interpupillary distance of IPD and D_1 away from the screen. An image with apparent position of D_2 away from the screen would require two different projections S apart from each other on the screen. If the image is in front of the screen , D_2 would be negative and the shift would be in the opposite direction.

5cm and an interpupillary distance of 6.3cm was used, which is the average adult interpupillary distance (Dodgson, 2004). These measurements were used to create the stimuli. Red and green images were created using the RGB color filters in Adobe Photoshop. The two images were perspective warped according to the angle of convergence of the eyes.

Detection of depth. Stimuli for detection of depth flickered between pictures which had depth information and no depth information. Stimuli with pictorial depth utilized shading as a pictorial depth cue by using the drop shadow function in Photoshop. Five images of a rectangle that subtended a visual angle of 7.6 x11.4 degrees were created. The five images were: *control condition* which only contained the rectangle; *pictorial condition* which had a drop shadow behind the rectangle; *stereo condition* in which the rectangle was viewed with disparity that made it appear 5cm in front of the screen; *combined condition* in which the rectangle had both a from the *pictorial condition* and disparity from the *stereo condition*; *conflicting*, which was the combination of the *pictorial condition* and disparity which made the rectangle appear 5cm behind the screen. Since SSVEP uses flickering pictures to detect neural activity corresponding to specific percepts of depth, the five images were paired up to create four conditions: *control-*

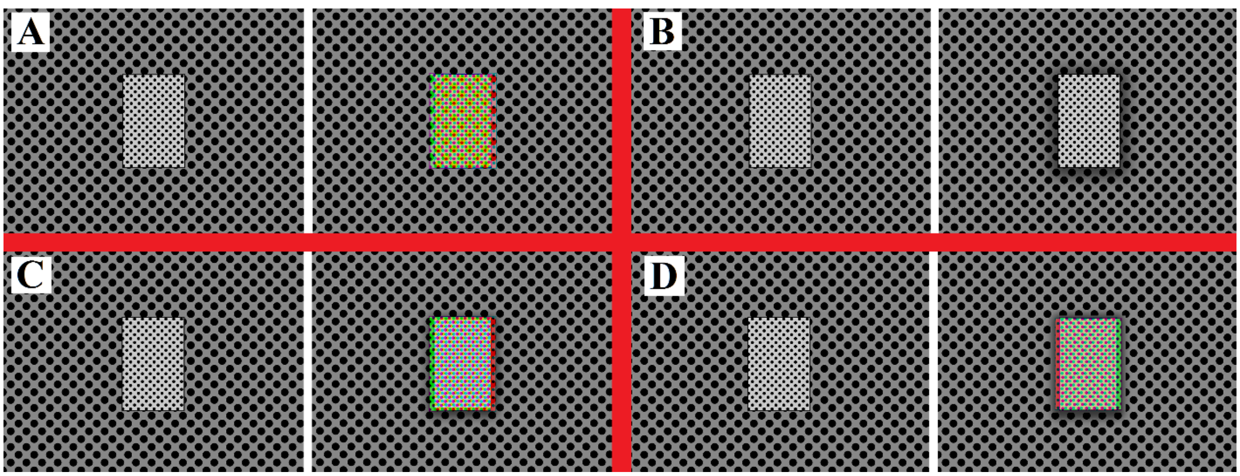

Figure 3. All four detecting condition stimuli. A) Control-stereo, which induces the detection of stereo depth. B) Control-pictorial, which induces the detection of pictorial depth. C) Control-combined, which induces the detection of combined depth. D) Control-conflicting, which induces the detection of conflicted depth.

stereo (Figure 3A), *control-pictorial* (Figure 3B), *control-combined* (Figure 3C) and *control-conflicting* (Figure 3D).

Alternation of depth. Stimuli for alternation of depth flickered between two pictures with had different amounts of depth. Stimuli with pictorial depth utilized perspective as a pictorial depth cue by placing a perspective grid in the background. Eight images were created, four of which had a larger rectangle subtending a visual angle of 10.9 x 16.2 degrees and the other four had a smaller rectangle of 3.27 x 4.9 degrees, maintaining the same aspect ratio between rectangles. The larger rectangle was viewed with disparity that presents it 4 cm behind the screen, while the smaller rectangle had disparity that presents it 12 cm behind the screen during stereo and combined conditions. These eight images were grouped into four pairs, each pair included one larger and one smaller rectangle. The *control condition* had the rectangles on a gray background and no disparity (Figure 4E); the *pictorial condition* had the rectangles on a perspective grid, so the rectangle would appear to move back and forth (Figure 4F); the *stereo condition* had disparity information presented with the rectangles on a gray background (Figure 4G); the *combined condition* had both disparity and a perspective grid (Figure 4H).

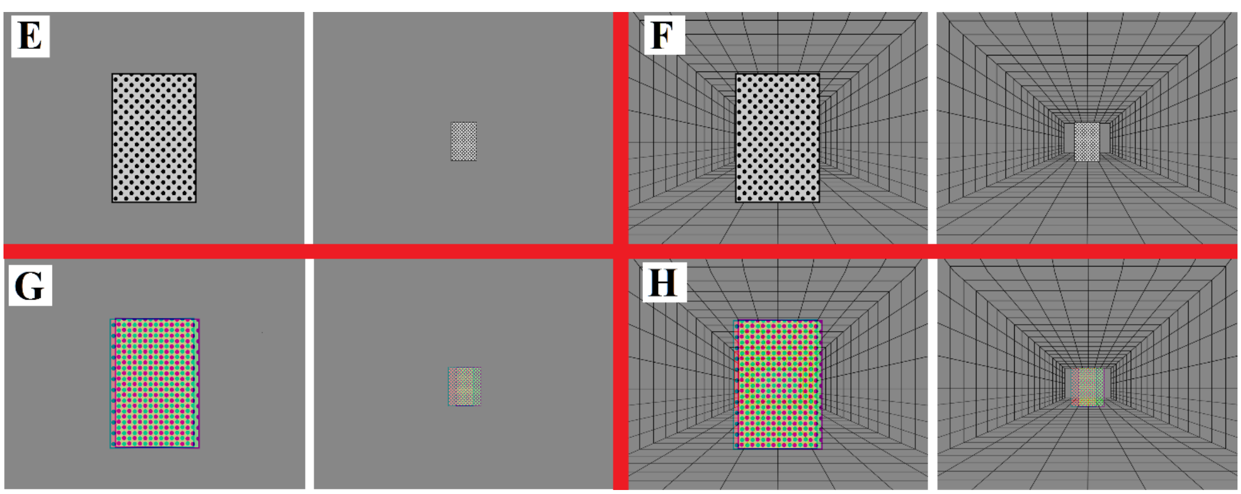

Figure 4. All four alternating condition stimuli. E) Control, which induces activity related to the alternation of size. F) Pictorial, which induces the perception of alternating pictorial depth. G) Stereo, which induces the perception of alternating stereo depth. H) Combined, which induces the perception of alternating combined depth.

Data Analysis

Pre-processing. Each subject's EEG recording was first pre-processed with a band pass filter of 0.5 – 40 Hz, filtering high and low frequency noises, then it was split into nine 20 second epochs and fast Fourier transformation (FFT) was run on each epoch. This transformation breaks down a wave into its frequency components, plotting the magnitude of each frequency on a power spectrum (Figure 5).

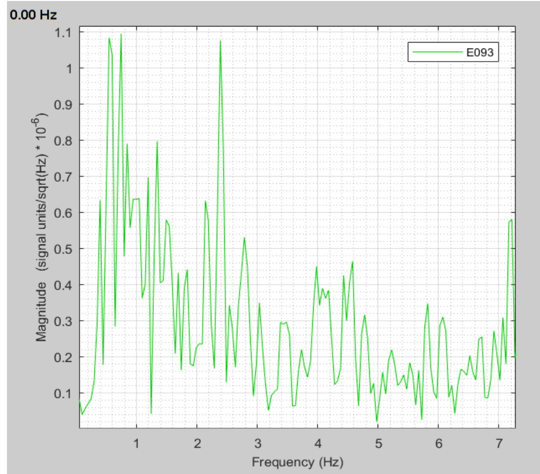

Figure 5. FFT power spectrum for checkerboard condition at electrode 93. (Occipital parietal)

Plotting magnitude. Due to the usage of a high density EEG net, heat maps were most suitable and efficient in pinpointing activated electrodes. However, due to the small magnitude ($\mu V/Hz^{0.5}$) of frequency responses, any noise or artifacts could cause noticeable differences in the magnitude of neural activity between electrodes, which made it unreliable to plot magnitudes on a heat map. The magnitude of a target frequency does not give information on how strong is the magnitude compared to frequencies, so in order to quantify the idea of a peak and take the average activity strength of the electrode into account, I proposed and implemented a variable called the *relative peak strength* (RPS).

Relative peak strength. The relative peak strength (see Equation 2, overleaf) is a measure of the difference in magnitude of a target frequency (V_{target}) and the average magnitude of the successive frequencies (V_{avg}) relative to the average magnitude. This measurement is similar to the signal-to-noise ratio (SNR), but it has more specific targets for comparison. The scale starts at 0 and anything above 1 qualified as a peak.

$$RPS = \frac{V_{target} - V_{avg}}{V_{avg}} \quad (2)$$

I programmed an algorithm in MATLAB to calculate the 2.4 Hz RPS for each electrode relative to the average magnitude of frequencies from 3-8 Hz, a range that includes all frequencies of theta waves and is near the target frequency. The algorithm would then plot these values on a heat map to help visualize the data and look for regions of interest.

Statistical analysis. Student's t-tests were run between the average RPS in regions of interest under alternating control condition and experimental conditions. Statistical tests were not run between detection conditions due to the lack of a control scenario. Next, a theoretical combined depth condition was created based on the activated regions from pictorial and stereo depth. This condition was made on the assumption that activated regions with the higher RPS from pictorial and stereo depth perception would remain activated in combined depth perception. This theoretical condition would be used to model the simultaneous perception of stereo and pictorial depth based on the structuralistic approach. Finally, two tailed t-tests were run between the overall RPS of experimental combined scenarios and stereo, pictorial and theoretical conditions for both alternation and detection of depth to compare the amount of neural activity.

Only the posterior of the head was considered, since it contains most regions of the brain that were responsible for visual perception. Alpha was set at 0.05 for all t-tests.

Results

RPS heat maps. The six resulting RPS heat maps are shown below: alternating pictorial (Figure 6), alternating stereo (Figure 7), detection pictorial (Figure 8), detection pictorial (Figure 9), alternating combined (Figure 10) and detection combined (Figure 11).

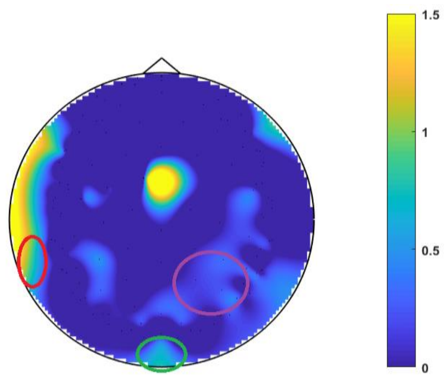

Figure 6. RPS heat map for alternation of **pictorial** depth (control subtracted).

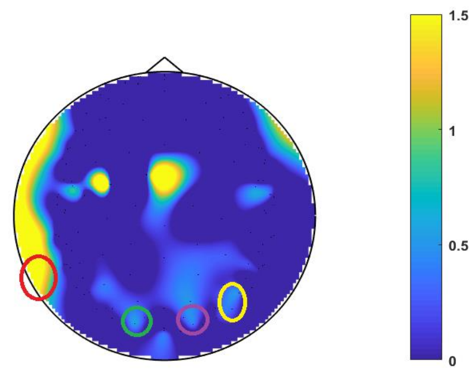

Figure 7. RPS heat map for alternation of **stereo** depth (control subtracted).

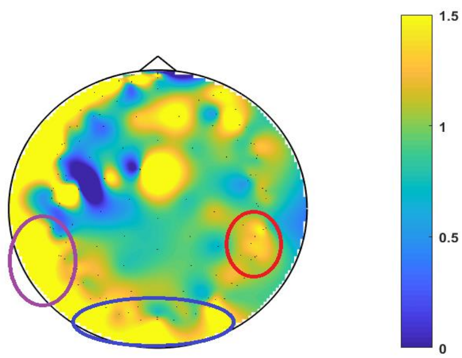

Figure 8. RPS heat map for detection of **pictorial** depth.

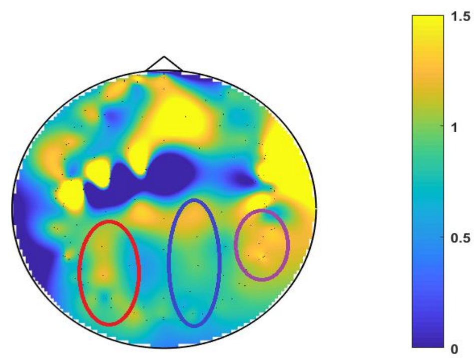

Figure 9. RPS heat map for detection of **stereo** depth.

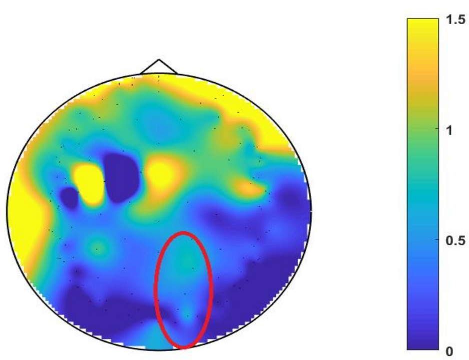

Figure 10. RPS heat map for **alternation** of combined depth.

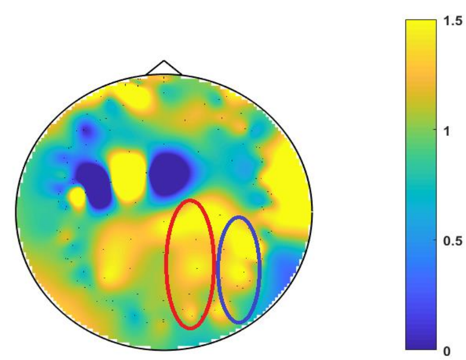

Figure 11. RPS heat map for **detection** of combined depth.

Condition comparisons. The mean RPS for all posterior electrodes for each scenario was computed to quantify and compare the neural activity in each scenario. Two-tailed t-tests were run to compare pairs of conditions in Table 1, only visually observed trends were tested. Comparisons involving the control-conflicting scenario yielded no significant results.

Table 2 shows the results of t-tests on observed trends. The mean RPS in alternation of combined depth was observed to be smaller than the alternation of pictorial (p=0.1065), stereo (p=0.1143) and significantly smaller (p=0.003) than theoretical conditions. The mean RPS in detection of combined depth was not significantly different than the detection of pictorial (p=0.4884) or stereo (p=0.3901) and was observed to be smaller than the theoretical condition (p=0.136). The mean RPS of alternation conditions was significantly greater than detection conditions (p=0.0187).

Table 1.
Mean RPS table.

Condition	Mean RPS
AltP	0.6583
AltS	0.6607
AltCOM	0.2733
AltTheo	1.1957
DetP	0.9455
DetS	1.0776
DetCOM	1.0973
DetTheo	1.7004

Table 2.
Results of two-tailed t-tests comparing mean RPS values. (Significant results highlighted)

Condition	p
AltP>AltCOM	0.1065
AltS>AltCOM	0.1143
AltTheo>AltCOM	0.003
DetP<DetCOM	0.4884
DetS<DetCOM	0.3901
DetTheo>DetCOM	0.136
Alt<Det	0.0249

Discussion

Neural correlates. T-tests were ran on individual electrodes to test if the RPS value in the experimental condition significantly differ from the control condition. None of these T-tests returned significant results.

Visual inspection. The RPS heat map for alternating pictorial depth (Figure 6) shows neural activity running from the occipital lobe to the right temporal love, while the RPS heat map for alternating stereo depth (Figure 7) shows neural activity extending from the occipital lobes to the parietal lobe.

The RPS heat map for pictorial depth detection (Figure 8) shows activity extending from the occipital lobe (blue circle) to the right temporal lobe (red circle) and left temporal lobe (purple circle). For stereo depth, the right temporal lobe (purple circle) was observed to respond to the stimuli, while weaker activity was observed to extend form the occipital lobe up to the parietal lobe (blue circle) and right parietal-temporal lobe (red circle) (Figure 9).

Figure 10shows activation from occipital to parietal regions (red) during the alternation of combined depth; Figure 11 shows activations from occipital regions extending into parietal (red) and temporal (blue) regions during the detection of combined depth.

Two-streams hypothesis. The extension of neural activities seem very similar to the streams mentioned in the two-streams hypothesis. According to the two-streams hypothesis, visual information tends to travel along two different streams – the dorsal stream and ventral stream (Goodale & Milner, 1992). The dorsal stream runs from the occipital lobe to the parietal lobe; the ventral stream runs from the occipital lobe to the temporal lobe. Visual observations of the results suggest neural activity related to depth perception followed these streams. Specifically, neural activity was observed along the dorsal stream during the alternation of stereo depth (Figure 7) and along the ventral stream during the alternation (Figure 6) and detection of pictorial depth (Figure 8). The detection of stereo depth had activation in both streams (Figure 9).

Stereo depth was observed to induce activation in dorsal areas. Since stereo depth is the most reliable type of depth perceived in real life and is believed to guide visuomotor tasks (Levi, et al., 2015), the fact that stereoscopic visual information is processed through the dorsal stream would seem reasonable, as the dorsal stream is responsible for action-related information. On the other hand, pictorial depth was observed to be processed in the ventral stream. One possible reason is that since pictorial depth only provides relative depth information, it only serves as a guideline towards spatial information – making pictorial depth responsible solely for the reconstruction and comparison of depth, not the quantification of it. Despite the lack of significant results to support this claim, observations suggest that the perception of stereo and pictorial depth are processed in different neural streams, and hence each serves a different purpose in the processing of spatial information.

Combined depth perception. Due to lack of significance of ROI in neural correlate analysis, more general approaches were taken in analyzing combined depth perception, such as stream observation and overall RPS.

Rejection of H_0. The null hypothesis took a structuralistic approach towards combined depth perception, hypothesizing that the combined depth perception would be solely the sum of pictorial and stereo depth. Were this the case, the EEG would show neural activity similar to the theoretical condition, which models the simultaneous perception of stereo and pictorial depth.

The results of two-tailed t-tests show that the experimental combined condition had significantly less activity than the theoretical during alternation of depth ($p=0.003$). During detecting depth, the experimental condition was observed to have less activity than the theoretical, despite the lack of significant result ($p=0.136$). These results make a strong point that the perception of combined depth is not solely the sum of the stereo and pictorial depth, but rather the result of integrating and re-analyzing both stereo and pictorial depth information.

Acceptance of H_1. The working hypothesis suggests that perceiving combined depth would yield different neural activity than during the perception of stereo and pictorial depth. Based on the statistical and observed difference between the theoretical and experimental combined depth conditions, specifically the absence of ventral stream activation in combined depth perception, it can be said that combined depth acts like a Gestalt and is not a mere sum of stereo and pictorial depth perception.

Streams. Activity in the dorsal stream was observed during the alternation of combined depth and stereo depth, while activity in both streams was observed during the detection of combined depth and stereo depth. When having a common perceptual task (alternation or detection), neural activities during combined depth perception were observed to resemble those of stereo depth. This suggests stereo depth plays a prominent role in the percept of combined depth. The fact that neural activity during combined depth perception does not resemble pictorial depth also implies that there were interactions between the dorsal and ventral streams.

Perceptual interactions. Although the results were not significant, interesting trends were seen in the two-tailed t-test results. The combined perception of depth had less activity than pictorial ($p=0.1065$) and stereo ($p=0.1143$) during alternation, but similar activity than pictorial ($p=0.4884$) and stereo depth ($p=0.3901$) during detection. The lack of significance was likely due to the low signal-to-noise ratios of EEG analysis and the low number of subjects.

Based on observed similarities between stream activities in stereo and combined depth in the previous section, stereo depth would be the predominant type of depth perceived in combined depth. Following this idea, pictorial depth information would have a supplementary role in combined depth perception, causing different neural activities in stereo and combined depth.

Pictorial depth in alternation. Both alternation of combined depth and stereo depth induced neural activity in the dorsal stream, however combined depth had smaller RPS values despite being the combination of two depth percepts. One possible explanation for this is that, since the alternation of depth is a series of continuous comparisons of depth, the relative depth information in pictorial depth acts as a supplement that facilitates the perception of depth, reducing the intensity of brain activity needed to perceive the alternation of depth.

Pictorial depth in detection. The detection of stereo depth and combined depth both induced neural activity in dorsal and ventral streams. However, the mean RPS for combined depth is similar to both stereo and pictorial depth. Note that the detection stimuli set had the control rectangle as a part of the stimuli, so subjects would have had to quantify depth without a reference. One possible explanation for the similar RPS values is that the brain is unable to utilize relative depth information from drop shadows to supplement stereo depth in quantifying depth. Instead the brain disregards pictorial depth and relies solely on stereo depth, since it provides quantitative depth information. This explains the similar neural activity in combined depth and stereo depth.

Alternation vs. Detection. Results showed that the detection of depth had significantly larger RPS than the alternation of depth ($p=0.0249$). This implies that it is easier for the brain to compare depth than detect depth, which supports the claim that perceiving alternation of depth is a series of comparisons, while detecting depth requires quantifying depth information.

Conclusion

Heretofore unreported in the literature, this study successfully utilized a steady-state visually evoked potential (SSVEP) paradigm to quantify neural activity during combined depth perception by implementing a novel variable. Ventral stream activity was observed during pictorial depth perception and dorsal stream activity during stereo depth perception, suggesting that the two percepts play different roles in analyzing spatial information. This study is the first to quantitatively look into the combined perception of depth, the combination of stereo and pictorial depth perception, which was demonstrated to behave like a Gestalt. In this Gestalt of visual depth, stereo depth was suggested to play a predominant role; pictorial depth had different roles, either supplementary or playing no role at all, depending on the task. This highlights the radically different interactions between the dorsal and ventral streams.

The association between depth percepts and stream activity is an interesting connection that requires further conformational research and studies, as it may lead to further clarification on the functional connectivity of the brain and the processing of visual information. By investigating depth perception, we can decode the process of perceiving depth and realness, allowing us to understand how we reconstruct the visual world we perceive.

References

Akay, A. (2009). A brain electrophysiological correlate of depth perception. Neurosciences 2009; Vol. 14 (2).

Backus, B. T., Fleet, D. J., Parker, A. J. & Heeger, D. J. (2001). Human cortical activity correlates with stereoscopic depth perception. Journal of Neurophysiology. 2001 October 4; 86 (4): 2054-2068.

Bowman, D. A. & McMahan R. P. (2007). Virtual reality: How much immersion is enough? Computer, volume 40, no 7, pp 36-43. July 2007. doi:10.1109/MC.2007.257

Bulthoff, H. & Mallot, H. (1988). Integration of depth modules: stereo and shading. J Opt Soc Am A. 1988 Oct;5(10):1749-58.

Burle, B., Spieser, L., Rogers, C. L., Casini, L., Hasbroucq, T. & Vidal, F. (2015). Spatial and temporal resolutions of EEG: Is it really black and white? A scalp current density view. International Journal of Psychophysiology, 97(3), pp. 210-220.

Cai, T., Zhu, H., Xu, J., Wu, S., Li, X. & He, S. (2017). Human cortical neural correlates of visual fatigue during binocular depth perception: An fNIRS study. PLoS ONE. 12(2): e0172426. 2017 Feb 16. doi:10.1371/journal.pone.0172426.

Dodgson, N. (2004). Variation and extrema of human interpupillary distance. Proceedings of SPIE, 5291, 36-46.

Gillmeister, H. & Eimer, M. (2007). Tactile enhancement of auditory detection and perceived loudness. Brain Research. Volume 1160, 30 July 2007, Pages 58-68.

Gogel, W. C., & Dasilva, J A. (1987). Familiar size and the theory of off-sized perceptions. Perception & Psychophysics, 41, 318–328.

Goodale M. & Milner A. (1992). Separate visual pathways for perception and action. Trends Neurosci 15:20-25.

Goodale, M.A. (2014). How (and why) the visual control of action differs from visual perception. Proc Biol Sci. 2014 Jun 22; 281(1785): 20140337. doi:10.1098/rspb.2014.0337

Hebart, M., & Hesselmann, G. (2012). What Visual Information Is Processed in the Human Dorsal Stream? Journal of Neuroscience, 13 June 2012, 32 (24) 8107-8109. doi:10.1523/jneurosci.1462-12.2012

Hidaka, S. & Ide, M. (2015). Sound can suppress visual perception. Scientific Reports 5, Article number: 10483. doi:10.1038/srep10483.

Hogendoorn, H. (2015). From sensation to perception: Using multivariate classification of visual illusions to identify neural correlates of conscious awareness in space and time. Perception 44: 71–78. doi:10.1068/p7832.

Holmes, N., & Spence, C. (2006). Multisensory integration: Space, time, & superadditivity. Current Biology, 15. 2005, pp. 762-764

Hou, C., Pettet, M., Vildavski, V. & Norcia, A. (2006). Neural correlates of shape-from-shading. Vision Research 46, Issues 6–7, March 2006, Pages 1080-1090.

Ide, M. & Hidaka, S. (2013). Tactile stimulation can suppress visual perception. Scientific Reports 3:3453 (2013).

Johnston, E., Cumming, B. & Parker, A. (1993). Integration of depth modules: stereopsis and texture. Vision Res.1993 Mar-Apr; 33(5-6):813-26.

Koffka, K. (1935). Principles of Gestalt psychology. London, UK: Routledge.

Levi, D., Knill D. & Bavelier D. (2015). Stereopsis and amblyopia: A mini-review. Vision Research, 114 (2015), pp. 17–30.

Liu, B., Meng, X., Wu, G. & Dang, J. (2013). Correlation between three-dimensional visual depth and N2 component: Evidence from event-related potential study. Neuroscience, Volume 237, pp 161–169.

Malik, A. S., Khairuddin, R., Amin, H. U., Smith, M. L., Kamel, N., Abdullah, J. M., Shim, S. (2015). EEG based evaluation of stereoscopic 3D displays for viewer discomfort. BioMedical Engineering Online, 14, 21.

Mishkin, M., Ungerleider, L., Macko, K. (1983) Object vision and spatial vision: two cortical pathways. Trends Neurosci 6:414-417.

Milner, A. D. (2017). How do the two visual streams interact with each other? Exp Brain Res. 235(5): 1297–1308. Published online 2017 Mar 2. doi:10.1007/s00221-017-4917-4.

Norcia, A., Appelbaum, L., Ales, J., Cottereau, B. & Rossion, B. (2015). The steady-state visual evoked potential in vision research: A review. Journal of Vision, May 2015, Vol.15(4). doi:10.1167/15.6.4.

Parker, A., Smith, J. & Krug, K. (2016). Neural architectures for stereo vision. Philos Trans R Soc Lond B Biol Sci. 2016 Jun 19; 371(1697).

Rosemann, S., Wefel, I., Elis, V. & Fahle, M. (2016). Audio–visual interaction in visual motion detection: Synchrony versus Asynchrony. J Optom. 2017 Feb 23.

Schiller, P., Slocum, W., Jao, B. & Weiner V. (2011). The integration of disparity, shading and motion parallax cues for depth perception in humans and monkeys. Brain Res. 2011 Mar 4; 1377: 67–77.

Sekuler, R., Sekuler A. & Lau R. (1997). Sound alters visual motion perception. Nature 385, 308 (1997). doi:10.1038/385308a0.

Shams, L., Kamitani, Y. & Shimojo, S. (2000). Visual illusion induced by sound. Cognitive Brain Research, 14, 147-152.

Van Dromme, I.C., Premereur, E., Verhoef, B.E., Vanduffel, W. & Janssen, P. (2016). Posterior parietal cortex drives inferotemporal activations during three-dimensional object vision. PLoS Biol. 14(4):e1002445. 2016 Apr 15. doi:10.1371/journal.pbio.1002445

Wheatstone, C. (1838). On some remarkable, and hitherto unobserved, phenomena of binocular vision. Philosophical Transactions of the Royal Society of London, 33 (1838), pp. 371–394.