Vastness and Scene Perception

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Vastness as a spatial percept can be described as an almost endless distance in a scene (Klatzky, Thompson, Stefanucci, Gill, & McGee, 2017). Previous experimentation has assessed the accuracy of traditional depth cues, which have not been reliable in denoting distances over 100 meters, in perceiving extreme depth that characterizes vast scenes (Cutting & Vishton, 1995; Daum & Hecht, 2009; Loomis & Knapp, 2003). Increased depth associated with perceptibly distant objects should affect participant appraisal of object apparent size by appearing larger due to cognitive associations between occluding objects and vast scenery (Witt, Stefanucci, Riener, & Proffitt, 2007). In this experiment, we assessed the vastness of natural scenes by correlating relative size judgments of a ring superimposed into two successive scenes varying in vastness. Using apparent motion techniques developed by Maas, Johansson, Jansson, and Runeson (1971), a ring that oscillated in four dimensions (ratio, tilt of major axis, upward and downward motion and overall size) was projected over scenes of natural environments. Participants made relative comparisons between the size of two rings that were homogenous in size. We hypothesized that greater vastness in the background scene would relate to estimates of the ring as larger. The experiment resulted in an apparent and indirect measure of depth, given that size and distance are related (i.e., size-distance invariance hypothesis, Kilpatrick & Ittelson, 1953). Additionally, findings supported that presence of vastness has a perceptual effect on relative estimates of object apparent size overlaid on vast landscapes.

INTRODUCTION

Vastness can be defined as a perceptual experience incited by the presence of extreme spatial extent. Although vastness plays a critical role in extreme depth perception there has been little research on vastness or its effects on scene perception. Previous research suggests that traditional or metric depth cues lose utility at roughly 100 meters (Cutting et al., 1995; Daum et al., 2009; Loomis et al., 2003). As metric depth cues fail at denoting far spatial extents a sense of vastness becomes relevant when perceiving extreme depth. The experience of vastness is not mediated by extreme absolute or relative metric depth alone and additional attributes of an environment, including the presence of natural and large features, are relevant factors of the experience of vastness (Greene & Oliva, 2009; Joubert et al., 2007). Our research question inquires whether we can surmise vastness estimates of presented landscapes by measuring the degree of perceptual change between two landscapes. We hypothesize that vast geography affects size perception of superimposed objects.

Estimating Extreme Depth

Research testing the efficacy of binocular depth cues, in denoting vast landscapes, was performed by (Cutting & Vishton 1995; Proffitt & Caudek 2002). Binocular depth cues rely on disparity between opposing eye's perception to deduce distance. Binocular disparity has been shown to be unreliable at determining distances because the angle relationship between two eyes begins to homogenize as metric depth increases (Cutting & Vishton 1995; Proffitt & Caudek 2002). Monocular depth cues, such as occlusion and atmospheric perspective, provide both relative and apparent senses of depth even while viewing landscapes with considerable depth. However, these cues have not been researched as an estimation of vast scenery.

Previous research has attempted to find reliable mechanisms to define the perceptual experience of vastness. However, without absolute depth measurements there are no current estimations of the depth between two points. Oliva and Torralba (2002) noted, "In the absence of cues for absolute depth measurements as binocular disparity, motion, or defocus, the absolute distance between the observer and a scene cannot be measured." (p.1) Absolute distance measurements are not sufficient as a measure of vastness in a scene.

Due to the deficiency of previous research in achieving reliable predictors of vastness a different hypothesis was explored. Henderson and Hollingworth (1999) suggested that vastness is abstractly experienced through sensation of environmental features. This direction contrasted research which focused on using estimations of distance to develop a method to measure vastness in landscape. Research presented by Green and Oliva (2009) and Jourbert et al. (2007) attempted to operationalize vastness through environmental features (i.e., both natural or large).

In addition, environmental context's effect on distance perception has previously been studied by Witt, Stefanucci, Riener and Proffitt (2007). Five experiments from Witt et al. (2007) analyzed how variations of space beyond a target affected distance perception, which was measured by both blind walking and perceptual matching. In addition, environmental effects, in the form of proximity of background, noted to have had an effect on scene perception. In addition, Lappin, Shelton, and Reiser (2006) also researched that environmental context's effect on perceived distance and found that varying contexts, such as the lobby of a building or outdoors lawn, affected distance estimations.
Overall, this work suggests that context and specific features, such as open and large, are important to the distance estimation and may be an important consideration of determining proxies for vastness.

Vastness and Awe

Vastness has been studied as a subcomponent of the emotion awe. Aside from depth, an important subcomponent of awe is a need for cognitive accommodation, which is defined by Keltner and Haidt (2003) as an impeded assimilation of a scene into existing schema or mental models. Additionally, the experience of awe can be either a negative or positive experience (Keltner & Haidt, 2003). For example, previous work has showed the potential to experience a negative form of awe by using threatening stimuli (Gordon et al., 2017). Beyond this general link, previous work has examined the relation between emotion and spatial perception. For example, Maslow (1968) described an emotional experience following what he referred to as peak experience, “The experience is accompanied by a characteristic disorientation in time and space” as a contextual clue of experiencing vast scenery. Maslow’s description of peak experiences is moderately similar to awe when considering its description of spatial disorientation and its ability to provoke an emotional response.

Much research suggests additional positive and negative emotions have efficacy in manipulating depth estimation. Positive emotions were shown to alter spatial estimation of distance to a finish line (Cole, Riccio & Balcetis, 2014). By comparison negative emotions were shown to influence perception of height (Stefanucci & Proffitt, 2009; Teachman, Stefanucci, Clerkin, Cody & Proffitt, 2009).

Proposed Hypothesis and Experimental Task

We contend that that the presence of vastness, within a natural scene affects the perception of objects that are occluding vast geography. We assessed this hypothesis by overlaying an oscillating ring over a range of vast images (Mass et al. (1971). We predicted that greater vastness, would lead to participants rating the ring as larger. The perceptual experience of the occluding ring appearing larger is a sign that the depth, implied with greater vastness, affects object (i.e., size-distance invariance hypothesis; Kilpatrick & Ittelson, 1953).

Landscapes exemplifying greater depth should affect apparent size of superimposed objects. This prediction is supported by size-distance invariance hypothesis. The size distance invariance hypothesis uses visual angle, size, and distance to estimate apparent size of an object. Using this trigonometric relation, the object’s apparent depth is calculated.

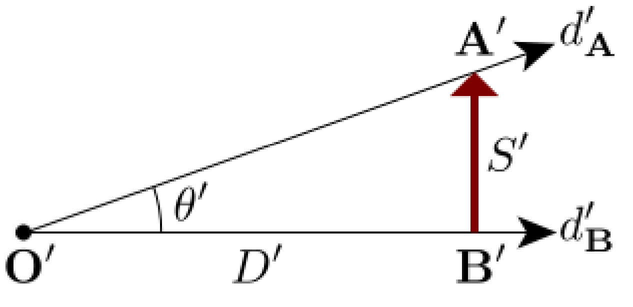


Figure 1. Visualization of *Size-distance relation*

METHODS

Participants

Ninety-two participants were recruited from the University of Utah Psychology Department participant pool for course credit. Eleven participants’ data were omitted from analysis due to errors with the computer program, experimenter errors, and vision issues. Additionally, twelve participants data were excluded upon analysis and discovery of unilateral experimental response (See Appedix for graph used to determine if participants were included based on response). Demographic information about age, sex, native language, and vision were recorded. The age range of participants was from 18 – 31 years old, with an average age of 19.2 (*S.D.* = 2.52). Participants were naive to the purpose of the experiment.

Materials and Apparatus

Materials included 50 images, which were previously rated for vastness. Images were collected from online sources. Some of the selected images were from Klatzky et al.’s (2017) work. The images are natural scenes that exclude manmade structures. The images are a mixture of natural scenes which include: horizon, far mountain, near mountain, field to trees, receding texture, forest, near rock/sand and close vegetation.

Two Images were compared during each trial. The first image that was being compared to was always the same. This method was done to establish a baseline from which to compare relative ring size across all images. A total of 49 trials of the relative apparent size and 51 of the vastness rating, were performed.

Figure 2. Example of *Vast and Non-vast images*

The experiment was constructed using both PsychoPy V 1.9 software (for vastness ratings) and Unity® version 2019.1. Rings were overlaid on the natural scenes using Unity software. The ring oscillated in four ways which will be: aspect ratio, tilt of the major axis, upward and downward motion and overall size. The aspect ratio describes relationship between the width and height of the computer monitor. The tilt of the major axis describes the ratio between the ring’s orbital vs rotational planes.

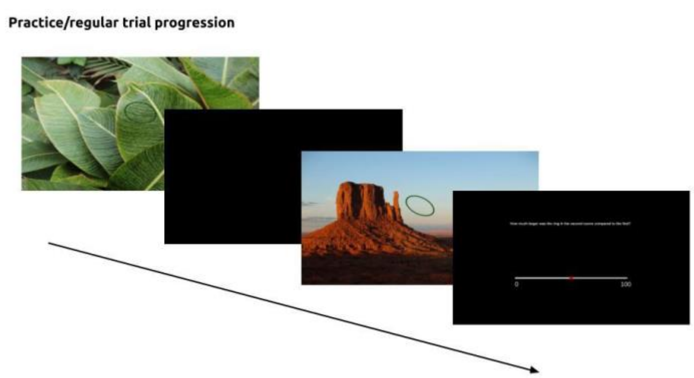
The experimental apparatuses used were a computer, monitor and mouse. The monitor resolution is 1900 x 1200 pixels. The operating system of the computers was Windows 7. For all measures, participants sat such that their eyes were approximately 70 cm from the monitor and viewed images that subtend a horizontal visual angle of 38 degrees and a vertical visual angle of 25 degrees. All images had a 3:2 aspect ratio.

Procedure

Upon arrival, participants read and signed the experimental consent document. The participants were positioned in front of a computer juxtapose to two pieces of tape marked where the chair's two front legs would rest. Participants were positioned so that their eyes were 70 centimeters from the monitor. Once the program began, participants were asked to complete demographic questions. Participants were then read an overview of the relative apparent size estimation task and were asked if they had any questions concerning the experimental procedure. Participants were asked to complete one practice trial to familiarize themselves with the experiment task and check for understanding. Following successful completion of the practice trial the participant began experimental trials. After completing the relative apparent size judgment task, participants subsequently began a task that involved rating how vast each image was. Finally, the participant was debriefed as to the purpose of the experiment and provided with contact information for additional inquiry. The experiment took roughly one hour to complete.

RESULTS

We had previously hypothesized that a greater sense of vastness in a scene would lead to an occluding and oscillating ring to appear larger. To assess this hypothesis, a mixed-effects model was performed to analyze estimates of apparent size. The R package lme4 (Bates, Maechler, Bolker, &



Walker, 2015) was used to assess fixed and random effects. This approach allows for assessing variability both within and between-participants. Below is the equation for the mixed-effects model where β_{0j} = intercept, $\beta_{1j}AS$ = effect of apparent size judgment (AS = Apparent size), and ε_{0j} = error term allowing for random effects.

$$Vastness_{ij} = \beta_{0j} + \beta_{1j} * AS + \varepsilon_{0j}$$

First, the null model was run with no predictors and only the random effects of participants included to assess the variance components of the data. The intra-class correlation was calculated and it was determined that roughly 9% of the variance in the data is due to differences between subjects, whereas the remaining variance is due to differences within subjects. Further, the null model revealed that the average vastness score was 52.20. Next, the full model was run with relative apparent size included as a fixed effect[1]. Random intercepts were allowed for participants and images. The results of this analysis revealed that the after inclusion of both fixed and random effects, the average vastness score was 54.32. Further, the intra-class correlation of the full model revealed that inclusion of relative apparent size as a fixed effect explains roughly 62% of the variation of the grouping structure (i.e., random intercepts for participants and images). Relative apparent size was positively significantly related to vastness such that for every one unit increase in relative apparent size, vastness ratings increased by .08, B = .08, *S. E.* = .02, $t(3076.61) = 5.41$, $p < .001$. Finally, comparing the null and full model using deviance scores, it was revealed that the full model fit the data significantly better than the null model, $\chi^2(2) = 4082.1$, $p < .001$.

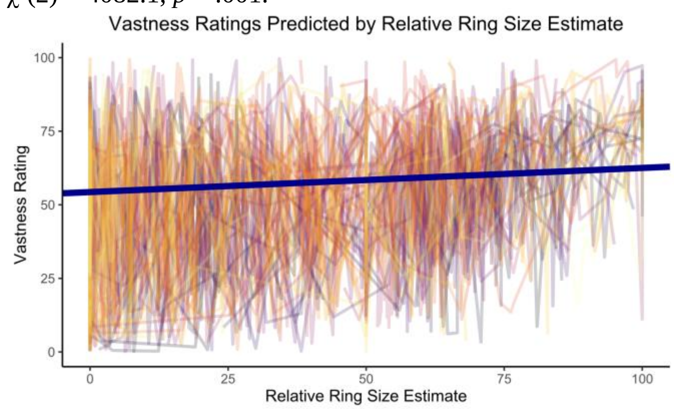


Figure 4. *Experimental Results*

DISCUSSION

Using an oscillating ring to predict vastness estimates our hypothesis was supported by the data and our results suggested that vastness is related to size estimates of objects in natural scenes. The proceeding experiment resulted in an apparent and indirect measure of depth, given that size and distance are related. Similar to the size-distance invariance hypothesis this work provides an additional method of estimation of apparent size of a stimulus. The concurring depth, however, is not calculated by a trigonometric relationship but is processed with unconscious visual discernment. Estimations of relative apparent size, in this occasion an oscillating ring, are concurrently related to the degree of vastness within the scene. Thus, we can account for a small, but significant degree of vastness in natural scenes.

Limitations

A threat to the internal validity of this study is the twelve participants data that was excluded. The excluded participants had given a homogenous response to all experimental trials as compared in Figure 5. Following are four possible explanations for this phenomenon. Firstly, the unilateral judgments of the participants may be explained by a belief that there was no size difference between the varying levels of the IV. Furthermore, it is possible this response stemmed from a separate individual perceptual effect on these individuals. Secondly, the response rate to this experiment may have been impeded by participant apathy. Thirdly, the use of convenience sampling and unobtrusive observation may account for the unilateral and ubiquitous answers given by disengaged participants. Fourthly, participants may not have understood experimental procedures or text and did not seek further explanation.

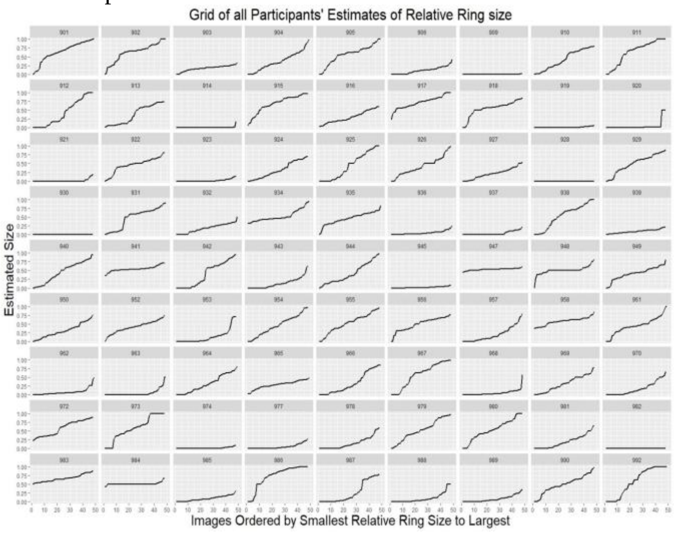


Figure 5. Visualization of Unilateral Responses

There is a longer temporal wait to recognize small objects in a landscape (Fei-Fei, Iyer, Koch, & Perona, 2007). The external validity of our results may not be applicable to urban environments as the numerous objects in a scene may limit attention and working memory capacity. Our exclusive use of natural environments may hint a context specific phenomenon. Further research may explore whether these same perceptual effects are experienced under city landscapes or mixtures between rural and urban geography. Understanding if and how this perceptual effect extends to various landscapes may extend the application of these results.

Implications to theory

The significance of these findings has two important implications. First, the results indicate that topography relates to absolute size estimation of objects in the scene. This result may lead to a better understanding of the perceptual experience of scenes exhibiting extreme depth. Second, these findings provide a new measurement for understanding perceptual associations of the extreme depth and scene perception. Not only should this measurement be further explored and developed, but it should be used to enhance rendering of virtual environments to create a better, more immersive experience.

Future research might test the effects of high levels of vastness on scene perception within the context of virtual reality. An immersive experience may change experimental outcome as visual and depth perception have been shown to change under the context of virtual reality. By comparison our findings may not exhibit external validity under the context of virtual reality as an immersive virtual experience may change experimental outcome.

Future research may benefit from additional practice trials in order to ensure participants understand experimental requirements and protocol. Furthermore, while direct observation may lead to observation effects the participants behavior may require remote monitoring and perchance intervention and explanation in order to reduce rare episodes of participant disengagement.

This research might be applied within the context of virtual reality to induce a sense of awe in viewers by applying attributes known to induce awe. Size perception of objects rendered in virtual reality have the possibility to be manipulated in order to accurately mimic natural settings and increase the presence of awe.

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