EXPLORATION OF THE OBJECT-BASED WARPING ILLUSION:

Distortions of space due to objects and grouping

by

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ABSTRACT

Our perception of visual objects is amongst the most important aspects of our visual perception. While most illusions of space focus on depth or comparison cues, another class of object-based illusions elicit effects from their own innate properties. Whether or not these warping properties of illusions exist uniformly or separately between singular objects and strongly grouped objects is a topic of debate in visual perception literature. We further explore the object-based warping (OBW) illusion and the one-is-more (OIM) illusion in a set of two studies: the first of which studies the effects found in the OBW illusion on a continuum of objecthood, the second of which studies the combination of effects between the OBW and OIM illusions. The first study showed that grouped objects exhibit object warping effects, and these effects exist on a continuum directly correlated to objecthood strength. The second study showed that expansion effects increase uniformly with increasing objecthood, from two objects to one object. However, the second study provided contradicting results as well, where the compression effect increased uniformly from *one object to two objects*. This provides evidence for the potential distinction of processing between strongly grouped objects and singular objects.

Chapter 1

INTRODUCTION

Perception is a judgment of our surroundings; one that is, often, incorrect. The way we see the world around us is affected by both bottom-up automatic processing of our environment and top-down controlled processing. How we attend to visual stimuli depends on the task at hand and how we are used to orienting the world around us. Considering the vast number of ways this perception can be altered, there are countless visual perception illusions that take advantage of that fact. We can purposely trick our brains into seeing what is not really there and making judgements that are inaccurate to our environment (Andrea et al., 2004; Anton-Erxleben et al., 2007; Gobell & Carrasco, 2005; Makovski, 2017).

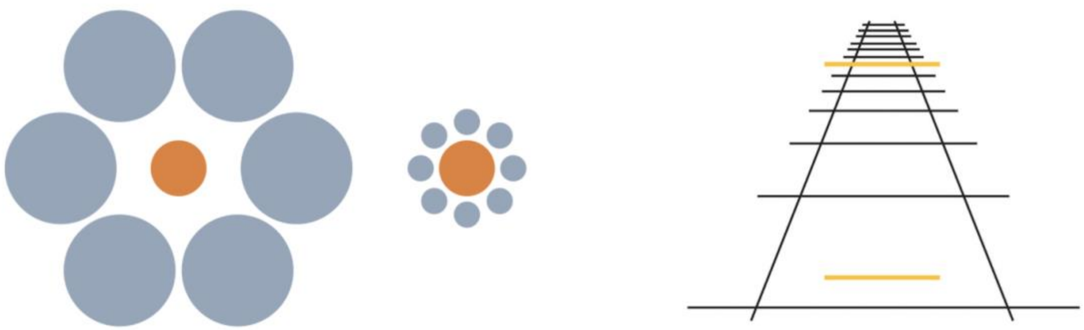


Figure 1. Illustration of Ebbinghaus Illusion (left) and Ponzo Illusion (right).

Many prominent illusions reveal specific ways in which our brain's visual areas function, such as the Ponzo Illusion and the Ebbinghaus illusion (shown in Figure 1). These illusions rely on perceptual cues such as comparison (Ebbinghaus) and depth perception (Ponzo) (Fisher, 1967; Titchener, 1901). However, there is a special class of visual illusions that do not rely on these fundamental cues, but rather are a result of object properties that have yet to be understood.

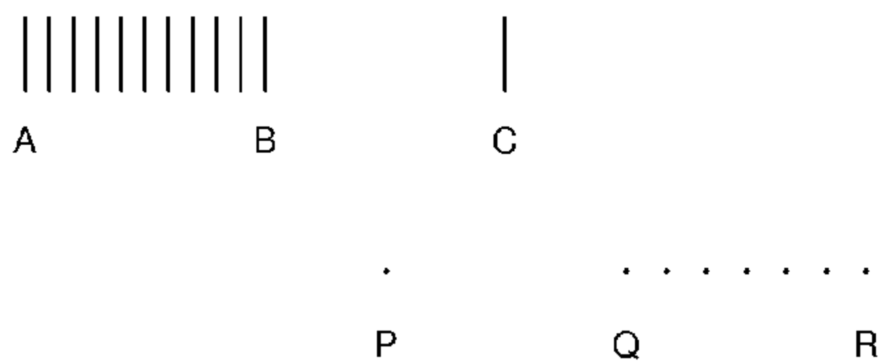


Figure 2. Illustration of the Oppel-Kundt Illusion in which segments AB and QR are perceived larger than segments BC and PQ, respectively. All corresponding segments are of the same length.

For example, the Oppel-Kundt Illusion is an illusion in which a space between two lines with multiple lines in between is seen as larger than an empty space between those same two lines (shown in Figure 2). In other words, "a filled space is larger than an empty space." This illusion cannot be described using comparison or depth perception, but rather the mere presence of objects distorts the space in which they occupy (Wackermann, 2017).

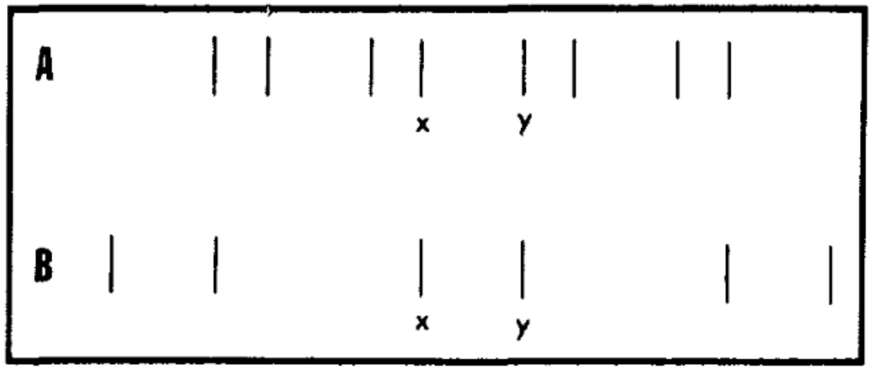


Figure 3. Illustration of the Gestalt Illusion, in which the space from XY in the top half of the illusion (separate groups) appears larger apart from the space between XY in the bottom half of the illusion (in the same group). Both segments are the same width apart.

Additionally, Coren & Girgus (1980) explore Gestalt illusions in which objects that are grouped together seem closer together than objects that are grouped separately (seen in Figure 3); the objects within a group experience a contraction effect while objects in separate groups experience a repulsion effect (Coren & Girgus, 1980). For further exploration of this class of object-based illusions, this study will utilize two notable illusions: the Object-based-warping (OBW) paradigm and the One-Is-More (OIM) illusion.

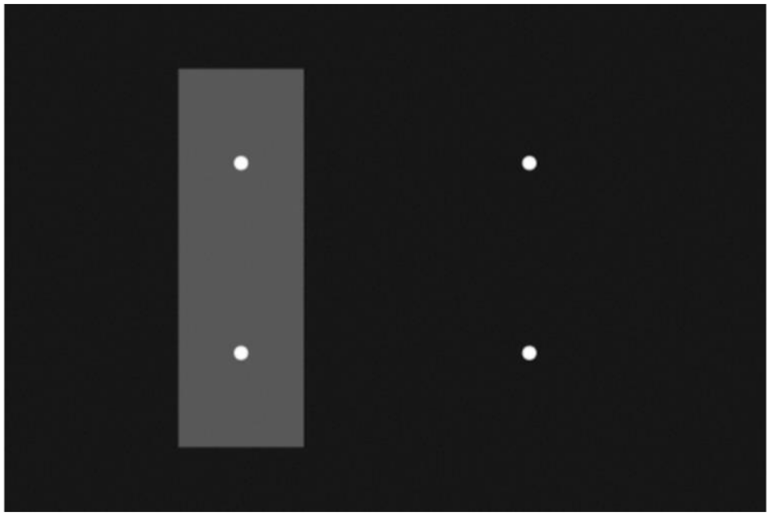


Figure 4. Illustration of the Object-Based Warping Paradigm in which a pair of dots on an object (left) appear larger than a set of dots of the same separation (right) not on an object.

In the OBW paradigm, the apparent distance of a pair of dots is warped by the presence of an object (shown in Figure 4). When a set of dots appearing inside an object are compared to a set of dots not inside an object, the first set of dots are perceived as farther apart than the latter (Vickery & Chun, 2010).

However, there are differences in the results depending on where exactly you place the two dots inside the object. If the two dots are placed closer towards the center of the object, you will perceive the dots to be farther apart than the ones outside the object. However, if you place the two dots closer to the top and bottom edges of the object, you will perceive the dots to be closer together than the ones outside the object (Vickery & Chun, 2010).

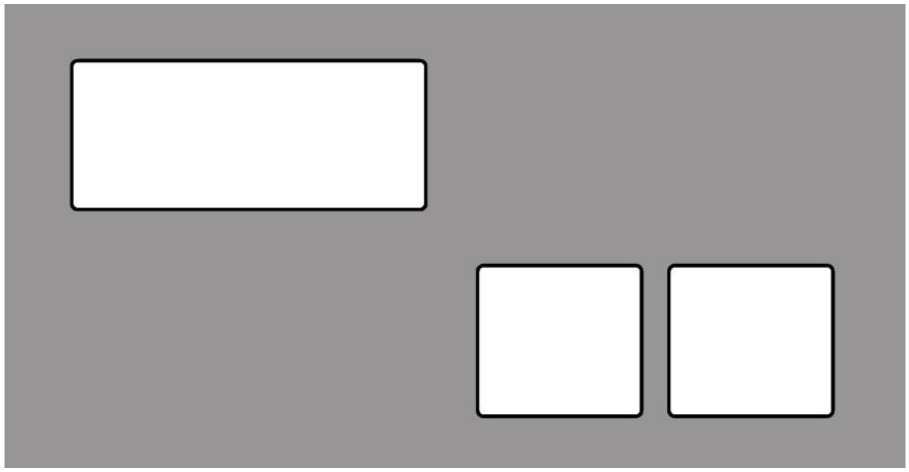


Figure 5. The One-Is-More paradigm, in which a continuous rectangle (left) appears longer than a set of discrete entities (right) of the same length.

In the OIM paradigm, a continuous rectangle appears longer than a set of discrete entities of the same length (shown in Figure 5). This means that, when shown a rectangle and a set of two squares with a gap in the center that are the same length and width, participants will be more likely to state the rectangle is longer than the set of discrete entities (Yousif & Scholl, 2017).

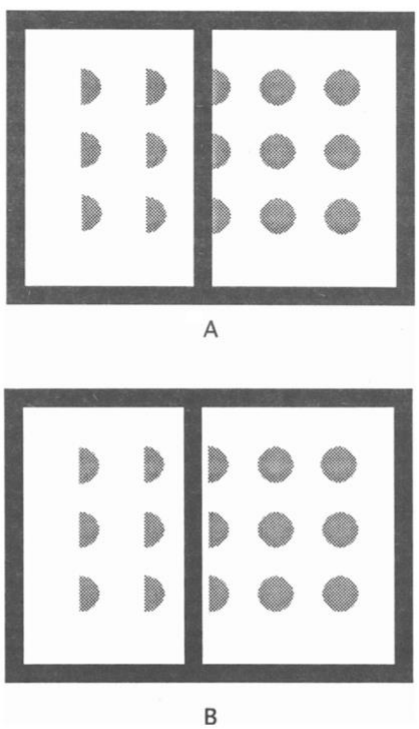
The theories supporting these two illusions are as follows: objects have inherent properties that cause them to warp the space inside them, either expanding or compressing the areas they enclose. These properties relate to how the visual system prefers objects and therefore more attention is directed towards them. This theory of object-based attention states that attention automatically spreads across the surfaces of objects or figures when you are focusing on that object (Vickery & Chun, 2010). In the case of the OBW illusion, participants focus more attention on the object and less so on the areas around that object, causing the space within the bounds of an object to be expanded and beyond the boundaries to be compressed. In the OIM illusion the continuous object has stronger objecthood. Therefore, the visual system prefers this object and spreads attention across it. The resultant of the two is that the continuous entity appears stretched relative to the discrete entity (Coren & Girgus, 1980; Vickery & Chun, 2010; Yousif & Scholl, 2017). However, the exact characterizations of these warping properties—how, why, and when they occur—are still unclear and require further exploration.

This exploration, however, cannot occur without first describing the basic theories of object perception. The most widely renowned theories of object perception are the Gestalt principles of grouping. The Gestalt principles include the laws of similarity, proximity, figure-ground, common fate, continuation, and closure. The principle of similarity states that objects that are similar to each other are grouped together. The principle of proximity states that objects that appear close together are aggregated into groups. The principle of common fate states that objects are grouped together if they are moving in the same direction and the same speed as each other. According to the principle of continuation, we assume objects are connected and continue with each other if they are aligned together. Lastly, the principle of closure states that objects are grouped together if they form a closed space together (Coren & Girgus, 1980; Todorovic, 2008). Another important principle to discuss is the figure-ground principle, in which visual scenes are always separated into two components: figure and ground. Figures are objects, and are closer to the perceiver, and ground is the background, and appear farther from the perceiver.

In addition to the Gestalt principles, there is the theory of Uniform Connectedness (UC). Palmer and Rock (1994) state this theory as, “closed regions of homogeneous properties—such as lightness, chromatic color, texture, and so forth—

tend to be perceived initially as single units” (Palmer & Rock, 1994). This theory, while sounding like the Gestalt principle of similarity, pertains to perception of objecthood, not object grouping. In other words, UC is used in perceptual processing to identify singular objects, not groups of objects, through the identification of boundaries.

However, what is a group of objects if not just an object itself? The answer to this question lies in the perceptual processing that occurs when looking at objects vs. a group of objects. Through the research of this processing, we can identify whether a strongly grouped object takes on the properties of a singular object, or if singular objects have their own set of properties that cannot be achieved regardless of the strength of grouping.



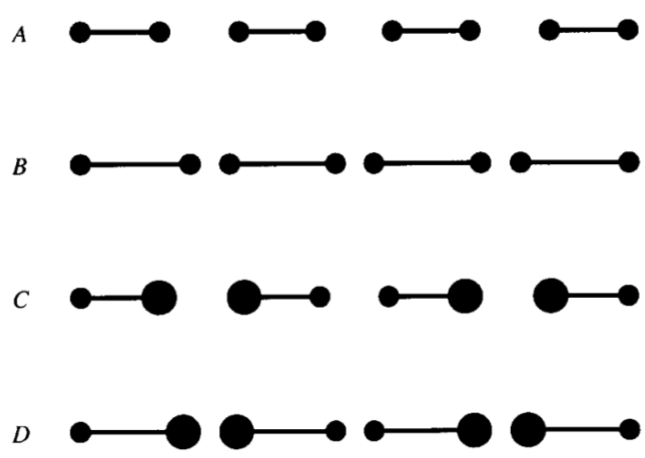


Figure 6. Shown on the left is a depiction of an illusion done by Palmer & Rock where a set of circles are grouped together only when a bar occludes half of a column of circles, showing that occlusion takes place prior to grouping. Shown on the right is a depiction of an illusion also done by Palmer & Rock where UC causes groups of similar & proximal objects to be grouped separately.

The sum of the literature on this topic is widely diverse and lends itself to many different debates. One of which is the debate on the primacy of UC; Palmer & Rock theorize that UC is the primary, entry-level mode of perceptual organization. Grouping is theorized to exist at a much later stage of processing (Palmer & Rock, 1994). Evidence of this is shown through our visual system's preferential processing towards occlusion over grouping as shown on the left in figure 6. In group A, the set of 9 circles to the right is grouped together, and the 6 half circles on the left are grouped together. Occlusion is enacted prior to grouping to assume the semi circles are full circles occluded by the bar and therefore belong in the circle group. However, if you move the half circles so that occlusion is no longer taking place, the 9 half circles are grouped together rather than with the 6 circles (Palmer & Rock, 1994).

Additionally, UC is found to be a stronger perceptual process and overtake perceptual organizations of grouping. As shown on the right in figure 6, different sizes of objects are grouped together when they are connected by a bar even when rules of proximity and similarity should cause grouping to occur in the opposite fashion (Palmer & Rock, 1994). These examples demonstrate that UC is deployed primarily in the visual system, and much earlier than grouping. Therefore, it raises the question of whether the perceptual process of grouping can be deemed the same as object definition through UC, and thus exhibit the same warping effects, when the two exist at such different stages of processing.

However, grouping has already shown to display warping effects. As shown in the Gestalt illusions in figure 3, grouped objects appear closer together than objects of separate groups; a clear extension of the object-based warping effects found in the OBW paradigm (Palmer & Rock, 1994). However, it is unclear how strong these effects are when compared to singular objects.

It is well established that object grouping can exist on a continuum. Namely, the strength of grouping of objects can be altered depending on how strong the principles of grouping are being employed. However, it remains unclear what the exact characteristics are at the end of this continuum. Can a set of objects be grouped together so strongly that they are perceived as a singular object? Or is the end of this grouping continuum simply strong grouping, with the perception of singular objects existing to a different continuum altogether?

With the previous information and examples taken together, it is unclear whether the brain, at least initially, identifies objects and groups of objects as perceptually the same. Furthermore, whether object warping effects extends uniformly to groups of objects as well. While it is unlikely there will be any one study that provides conclusive evidence on this debate, further characterization of the perceptual properties of objects and groupings of objects is needed to establish clarity of a relationship between the two.

To research this, we conducted two studies. The first study measured the warping effects found in the OBW paradigm in a group of objects, as well as whether those effects can be modulated by grouping strength. We expected a positive, linear correlation between warping effects and grouping strength. The second proposed study was a continuation of both the OBW and OIM paradigm. We utilized the object-based warping framework to compare estimated separations between dots on a singular object, dots on a grouped set of two objects, and dots not on an object. We expected to see the greatest warping effect in the singular object condition, no warping effect in the no object condition, and a medium warping effect in the grouped-object condition within each group of the same dot separation. Additionally, we expected to see an expansion effect at dot separations of 80 px and 200 px, with the greatest expansion effect at a dot separation of 80 px, and a compression effect at a dot separation of 300 px. A uniform increase in object warping effects from no grouping, grouping, and objecthood would provide evidence that objects and groups of objects are perceptually the same. However, other patterns of warping effects not following this continuum could provide evidence that they are perceptually different.

Chapter 2

METHODS

2.1 Objecthood Continuum Study

45 participants participated in the study for pay or college credit. All had normal or corrected-to-normal vision. Participants viewed the stimuli on a home monitor/laptop through an online study. The study was implemented through jsPsych, and participants used a mouse or touchpad. We excluded 8 participants who had more than a 10% error in the baseline condition.

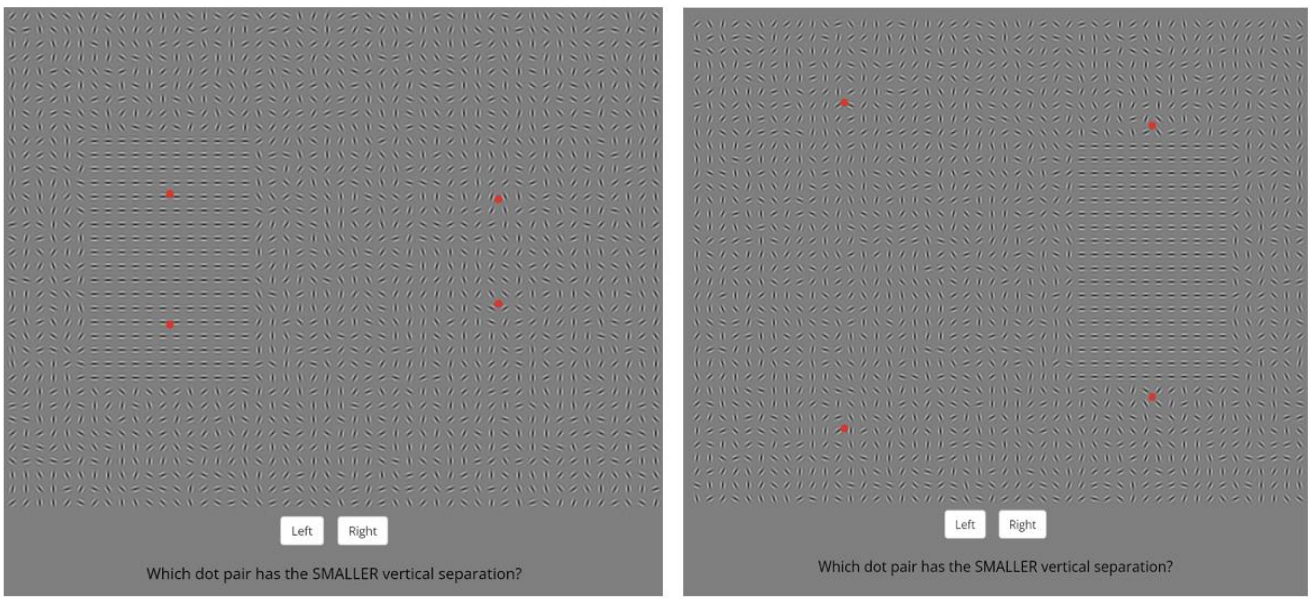


Figure 7. Sample trial of the Objecthood Continuum study of expansion reference separation (150 px, left), and compression reference separation (320 px, right).

During each trial, participants viewed a scene with two sets of red dots (10 px by 10 px), one above the other, on either side of the screen (Shown in Figure 6). The scene consisted of randomly oriented gabor patches of 16 px by 16 px. Adjustment dots were located on a uniform background of randomly oriented gabor patches and were adjusted by staircase intervals depending on the participant's responses. Reference dots were located on or surrounding a rectangle of gabor patches with a height of 288 px oriented at a coherency correlating to 1 of 4 conditions, and always remained the same distance apart throughout the staircase. Participants were instructed to indicate which set of dots were either smaller or larger by pressing a button on the screen with a mouse/trackpad corresponding to each of the sides.

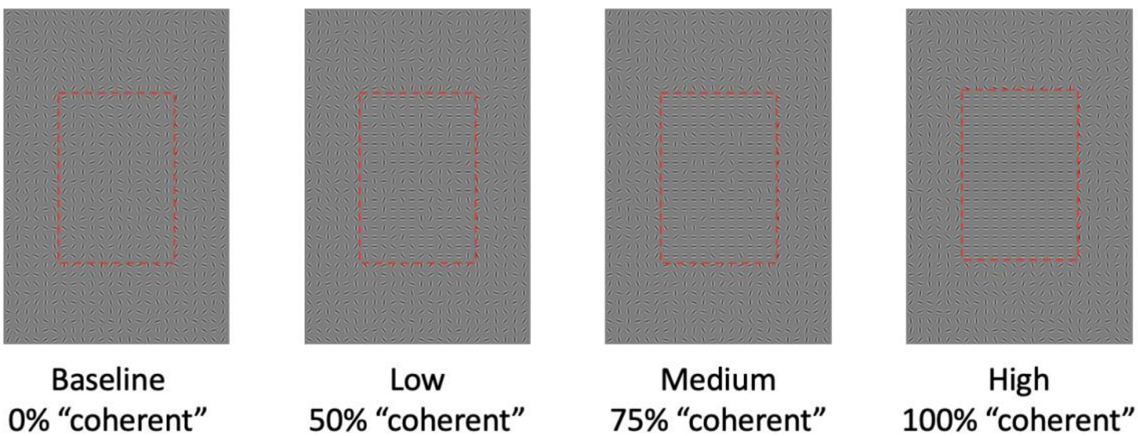


Figure 8. Each of the 4 conditions in the Objecthood Continuum study, varied by coherence of orientated gabor patches.

There were 4 conditions for each dot separation that differed based on coherence of gabor patch orientation. The baseline condition had 0% coherence, the low condition had 50% coherence, the medium condition had 75% coherence, and the high condition had 100% coherence (shown in Figure 7). Coherence is defined here as the number of gabor patches that are oriented in the same direction. There were two possible reference separations for each condition, one to produce expansion at a 150 px separation, and one to produce compression at a 320 px separation. The adjustment dots would start at either +/- 20% of the reference dot separation at the beginning of each trial.

We utilized the staircase method to establish the point of subjective equivalence (PSE) between the reference and adjustment dots. This would represent the percent difference between perceived and actual dot separation. After a total of 6 reversals had been achieved for all conditions, the experiment would end. The staircase steps started at 16 px and were halved after each reversal to a minimum of 2px. 3 of the last reversals would be averaged as the PSE. There were 8 possible conditions defined by the coherence of the "object" region, shown in Figure 7, and the position of the reference dots, with two starting points for each condition, which totaled to 16 groups of trials.

In each block, we interleaved the 16 possible conditions. Additionally, we randomized the sides the reference and adjustment dots appeared on. Half the participants were instructed to choose the smaller separation, and the other half were instructed to choose the larger separation (determined randomly).

2.2 Object-based Warping x One-Is-More Study

89 participants participated in the study for pay or college credit. All had normal or corrected-to-normal vision. Participants viewed the stimuli on a home monitor/laptop through an online study. The study was implemented through jsPsych, and participants used a mouse or touchpad. Any participants that scored above or

below the 10% estimated difference in any of the control "no object" conditions were excluded from the study.

During each trial, participants viewed a scene with two sets of red dots (10px by 10px), one above the other, on either side of the screen. Reference dots, which were embedded in an object, remained the same distance apart throughout the staircase. Adjustment dots were located on a uniform background and were adjusted by staircase intervals depending on the participant's responses. Participants were instructed to indicate which set of dots were either smaller or larger by pressing a button on the screen with a mouse/trackpad corresponding to each of the sides.

The object the reference dots were located on had 3 possible configurations: a rectangle (300 px), a set of discrete entities (2 squares of 100 by 110 px with an 80 px gap between them), or no object (on a uniform background). The reference dots appeared at a dot separation of 80 px, 200 px, or 300 px.

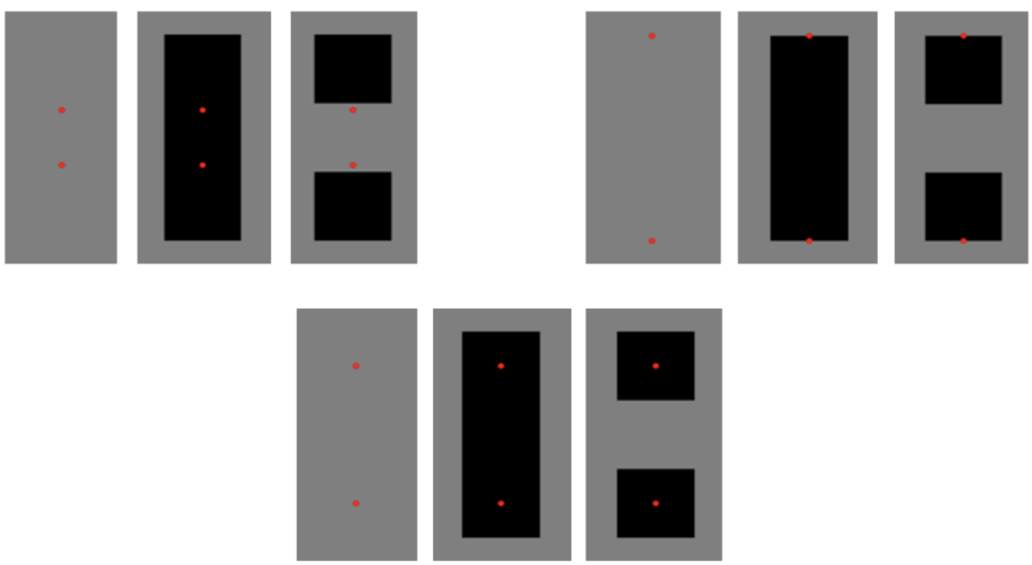


Figure 9. 9 conditions of the OBW x OIM study grouped by dot separation (from left to right, 80 px, 200 px, 300 px). In each group, from left to right, there is the no object condition, the object condition, and the two-object condition.

We utilized the staircase method to establish the PSE between the reference and adjustment dots. For each condition there were 2 staircases that occurred for the adjustment dots where they started at +40% or -40% of their corresponding reference dot separation. The staircase steps started at 16 px and were halved after each reversal to a minimum of 2px. After 6 reversals the staircase trial for that condition ended, and we averaged the last 3 reversals as the PSE. There were 9 possible conditions, shown in Figure 8, with two starting points for each condition, which totaled to 18 groups of trials.

Within each block, we interleaved the conditions shown. The sides the reference dots & adjustment dots appeared on were randomized. For half participants (determined randomly) instruction used the term smaller and for the other half - larger to control for confounding effects not related to the goals of this study.

Chapter 3

RESULTS

3.1 Objecthood Continuum Study

Percent error between PSE and reference dot separation were measured in each condition, a graph of results is shown in Figure 9. Our analysis focused on multiple comparisons within the compression conditions and the expansion conditions, a table of results are shown in Figure 10.

We completed a repeated measures ANOVA to measure the effect of coherency (null, low, medium, high) on mean percent errors in the compression condition group and showed a main effect $F(3, 108) = 8.857$, $p < .001$. Additionally, we completed a repeated measures ANOVA to measure the effect of coherency (null, low, medium, high) on mean percent errors in the expansion condition group and showed a main effect $F(3, 108) = 30.375$, $p < .001$. This data reveals that increasing coherency in all conditions resulted in stronger warping effects.

In the compression conditions, percent error between the no coherence and medium coherence conditions were found to be significantly different, $t(36) = 4.211$, $p < .001$, $d = 0.692$. Percent error between the no coherence and high coherence conditions were also found to be significantly different, $t(36) = 4.329$, $p < .001$, $d = 0.712$. No other significant differences were found between compression conditions.

In the expansion conditions, percent error between the no coherence and high coherence conditions were found to be significantly different, $t(36) = -10.115$, $p < .001$, $d = -1.663$. Percent error between the low coherence and high coherence conditions were also found to be significantly different, $t(36) = -6.859$, $p < .001$, $d = -1.384$. Additionally, percent error between the medium coherence and high coherence conditions were also found to be significantly different, t(36) = -6.044, p < .001, d = -0.994. No other significant differences were found between expansion conditions.

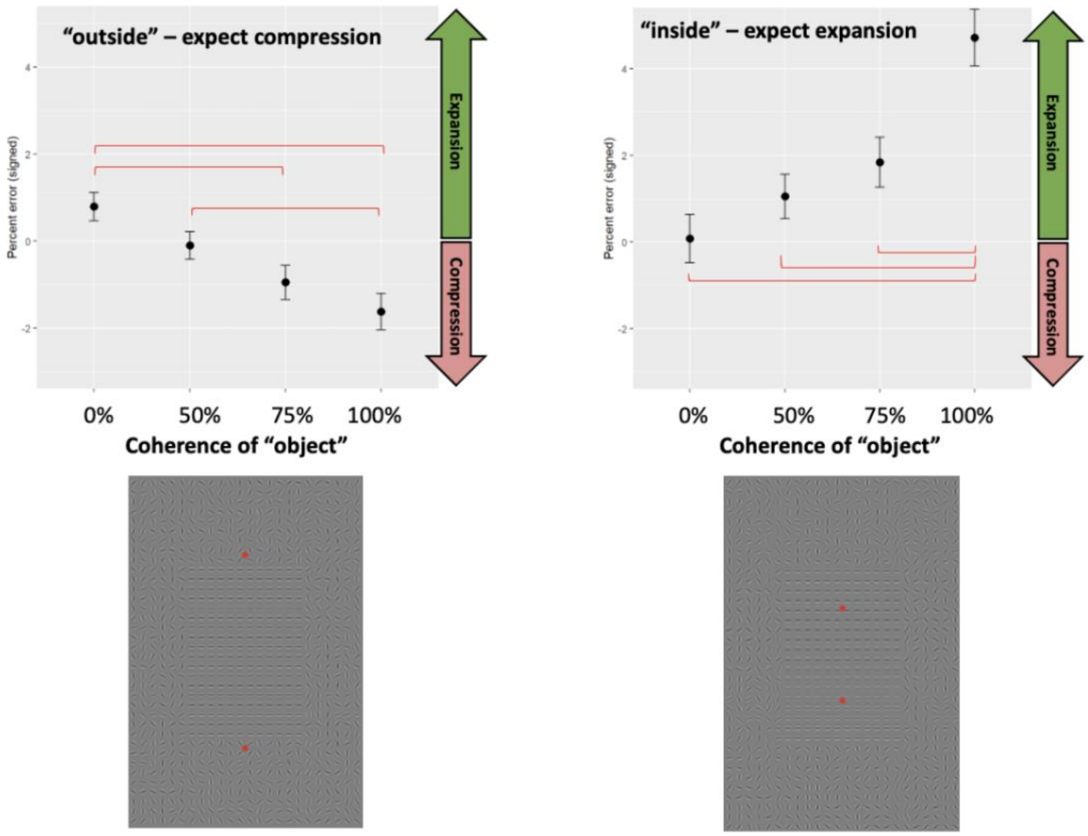


Figure 10. Graph of PSE across all 4 compression conditions (left) and the PSE across all 4 expansion conditions (right). Significance is indicated by a red bar connecting significantly different conditions. Above 0% error is considered expansion, while below 0% error is considered compression. Sample object stimuli at 100% coherence are shown below each graph.

Paired Samples T-Test

Paired Samples T-Test ▼

Measure 1		Measure 2	t	df	p	Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
Null_Expansion	–	Low_Expansion	−1.950	36	0.059	−0.321	−0.649	0.012
Null_Expansion	–	Medium_Expansion	−2.468	36	0.018	−0.406	−0.739	−0.068
Null_Expansion	–	High_Expansion	−10.115	36	< .001	−1.663	−2.158	−1.158
Low_Expansion	–	Medium_Expansion	−0.795	36	0.432	−0.131	−0.453	0.194
Low_Expansion	–	High_Expansion	−6.859	36	< .001	−1.128	−1.536	−0.709
Medium_Expansion	–	High_Expansion	−6.044	36	< .001	−0.994	−1.384	−0.594
Null_Compression	–	Low_Compression	2.063	36	0.046	0.339	0.005	0.668
Null_Compression	–	Medium_Compression	4.211	36	< .001	0.692	0.329	1.048
Null_Compression	–	High_Compression	4.329	36	< .001	0.712	0.346	1.069
Low_Compression	–	Medium_Compression	1.892	36	0.067	0.311	−0.021	0.639
Low_Compression	–	High_Compression	2.504	36	0.017	0.412	0.073	0.745
Medium_Compression	–	High_Compression	1.004	36	0.322	0.165	−0.160	0.488

Note. Student's t-test.

Descriptives

Descriptives

	N	Mean	SD	SE
Null_Expansion	37	−0.396	2.486	0.409
Low_Expansion	37	0.895	3.251	0.535
Medium_Expansion	37	1.405	3.911	0.643
High_Expansion	37	5.658	3.628	0.596
Null_Compression	37	0.507	2.090	0.344
Low_Compression	37	−0.374	2.104	0.346
Medium_Compression	37	−1.312	2.646	0.435
High_Compression	37	−1.737	2.788	0.458

Table 1: Paired Samples T-Test between every expansion condition and every compression condition (top) and descriptives table of every condition (bottom).

3.2 Object-based Warping x One-is-more study

Percent error between PSE and reference dot separation were measured in each condition, a graph of results is shown in Figure 11. Our analysis focused on multiple comparisons within each of the 3 dot-separation conditions (80 px, 200 px, and 300px), a table of results are shown in Figure 12.

We found that each of the conditions within the same dot separation (no object, object, and two objects) were significantly different from each other. The no object conditions yielded a 0 percent error, meaning neither a compression nor an expansion effect occurred. The object and two object conditions in the 80 px and 200 px condition groups yielded a positive percent error, meaning an expansion effect was observed. The object and two object condition in the 300 px condition group yielded a negative percent error, meaning a compression effect was observed.

The largest expansion effect was found in the one object condition at an 80 px dot separation and was significantly larger than the two-object condition at the same dot separation, $t(88) = 4.685$, $p < .001$, $d = 0.497$. The largest compression effect was found in the two-object condition at a 300 px dot separation and was significantly larger than the one object condition at the same dot separation, $t(88) = 7.481$, $p < .001$, $d = 0.793$. An expansion effect was observed in both the one object and two object condition at a 200 px dot separation, though less than the 80 px dot separation condition. The one object condition had a significantly larger expansion effect than the two-object condition at a dot separation of 200 px, $t(88) = 8.765$, $p < .001$, $d = 0.929$. All object conditions were significantly different than the no object condition at the same dot separation.

This data reveals that, for the expansion conditions, the one object conditions always resulted in stronger expansion effects than the two object conditions at the same dot separations. However, in the compression (300 px) conditions, the data shows a stronger warping effect in the two-object condition than the one object condition.

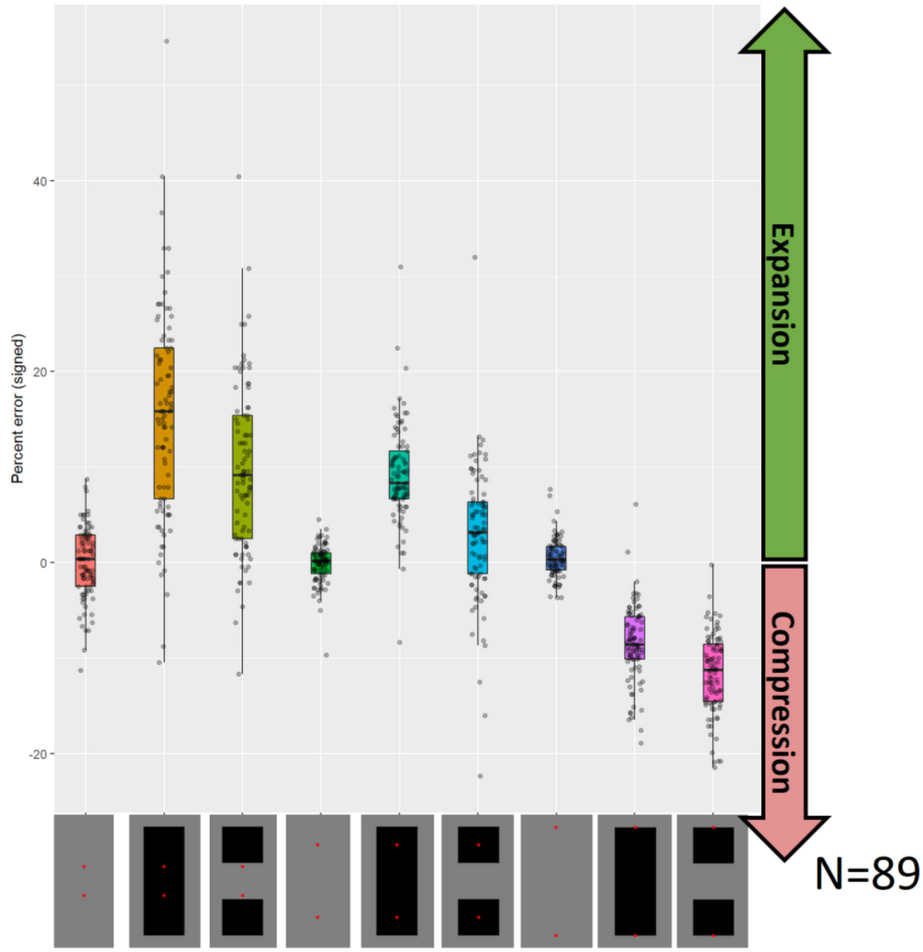


Figure 11. Graph of percent error across each condition. Above 0% error is considered expansion, while below 0% error is considered compression.

Paired Samples T-Test

Paired Samples T-Test

Measure 1		Measure 2	t	df	p	Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
NONE80	-	OBJECT80	−13.267	88	< .001	−1.406	−1.698	−1.111
NONE80	-	TWOOBJECT80	−10.328	88	< .001	−1.095	−1.356	−0.830
OBJECT80	-	TWOOBJECT80	4.685	88	< .001	0.497	0.275	0.716
NONE200	-	OBJECT200	−15.428	88	< .001	−1.635	−1.952	−1.315
NONE200	-	TWOOBJECT200	−3.690	88	< .001	−0.391	−0.606	−0.175
OBJECT200	-	TWOOBJECT200	8.765	88	< .001	0.929	0.678	1.176
NONE300	-	OBJECT300	18.441	88	< .001	1.955	1.597	2.308
NONE300	-	TWOOBJECT300	25.700	88	< .001	2.724	2.270	3.175
OBJECT300	-	TWOOBJECT300	7.481	88	< .001	0.793	0.553	1.030

Note. Student's t-test.

Descriptives

Descriptives

	N	Mean	SD	SE
NONE80	89	−0.005	3.767	0.399
OBJECT80	89	15.351	10.930	1.159
TWOOBJECT80	89	9.710	8.846	0.938
NONE200	89	−0.129	2.030	0.215
OBJECT200	89	9.236	5.190	0.550
TWOOBJECT200	89	2.787	7.062	0.749
NONE300	89	0.471	2.048	0.217
OBJECT300	89	−8.523	4.008	0.425
TWOOBJECT300	89	−11.602	4.163	0.441

Table 2: Paired Samples T-Test between every dot-separation condition (top) and descriptives table of every condition (bottom).

Chapter 4

DISCUSSION

Object-based illusions are unique in that they do not seem to follow the traditional characteristics that define spatial illusions—comparison, depth cues, etc. (Coren & Girgus, 1980; Fisher, 1967). Rather than creating properties of illusion to create a false perception, object-based illusions are falsely perceived themselves because of some innate property of objects. Additionally, object-based illusions lack an abundance of scientific exploration that might provide explanation and characterization of this property, how these illusions function, and how we perceive objects or groupings of objects. The present work provided insights that may lead to better models of such distortions.

Previous research on object-based illusions have revealed objects warp the space around them (Vickery & Chun, 2010; Yousif & Scholl, 2017). Oftentimes, they expand the space within them, causing the space within their boundaries to appear larger, and the space around their boundaries to appear compressed (Vickery & Chun, 2010). While it is shown that objects have these warping properties, it is unknown exactly how or why they warp space, what properties of objects create this illusion, and whether these properties extend to groupings of objects as well.

Therefore, the purpose of this study was to further investigate the OBW and OIM illusions and investigate how these illusions behave on a continuum of objecthood in order to better characterize how objects warp the space within and around them. In both studies 1 & 2, we found that expansion effects increase with increasing objecthood. In other words, as an object went from low grouping strength to high grouping strength to a singular object, the expansion effects of that object increased similarly. This set of results was not surprising, as they follow the reasoning behind the OBW and OIM studies; more concrete, singular objects exert stronger warping effects.

However, we found contradicting correlations for the compression effects in both studies. In study 1 we found that the compression effect increased with increasing organization. In study 2, it was revealed that the strongest compression effects were found in the two-object condition rather than the one object condition. This study showed increasing objecthood decreased the compression effect. There are two possible reasons for this, neither of which are mutually exclusive: an expansion effect still occurs at the dot separations designated for compression effects, and/or there is a difference in perception between strong groupings of objects and singular objects.

The first reason is that the expansion effect still occurs at the dot separations designated for the compression effects. The expansion effect was found to increase uniformly with increasing objecthood; whether the objecthood was increasing to a strongly grouped set of objects or a singular object. It is understood that the expansion effect is not modulated by the set of dots used in the OBW illusion, but rather revealed by these sets of dots. Therefore, no matter what separation the dots are displayed at, nor what effect they show, a general expansion of the space within the boundaries of the object is still expected to occur.

The decrease in compression effect in the one object condition vs. the two-object condition can be explained by a competing expansion effect. In the one object condition, the space within the object and between the dots is still expanded more than in the two-object condition. Therefore, it is not that there is less of a compression effect in the two-object condition vs. the one object condition but rather a stronger expansion effect in the one object condition than the two-object condition.

It is important to note that this competition of expansion vs. compression effect seems to only occur on the singular object condition; not in the strongly grouped conditions. If the competition were to happen in both groups, we wouldn't have seen the steady, uniform increase in compression effect as we increased grouping strength that we found in the first study. Rather, we would have seen a decrease in compression effect. The fact that the competition only occurs in the singular object condition, lends evidence to the later reason previously mentioned; singular objects are processed differently than grouped objects.

To elaborate on this reason, we look more closely at our second study. The decrease in the compression effect in the second study could show a difference in the perception between strongly grouped objects and singular objects, since the effect did not behave in the way that is expected. However, the expansion effect did increase uniformly with increasing object strength, even when the object switched from a grouped object to a singular object. Therefore, is there only differential processing for the compression effect between grouping/non-grouping? Or does this same distinction exist for the expansion effect as well (and thus, all object-warping effects), but our study was just not designed to reveal the distinction? More research and repetition of previous studies is necessary to examine whether a difference in processing exists between a grouping of objects and singular objects.

A possible limitation of this study may exist in the conditions we chose for both studies. Perhaps more conditions devoted to singular objects rather than strongly grouped objects in the first study, as well as more conditions devoted to strongly grouped objects rather than singular objects in the second study, would reveal information that could support or dispute distinctions in our object-processing systems. However, adding more conditions could potentially lead to adding more confounds to our study, so this limitation might best be handled through repetition of these two studies.

To conclude, we found that object-based warping effects can exist on a continuum directly related to objecthood and grouping strength. Additionally, we found that the expansion effect is displayed similarly in groups of objects as they are in objects. The compression effect however was found to increase uniformly with increasing grouping strength in the first study but decrease from one object (strongest objecthood) to two-object (weaker objecthood) in the second study. This might provide evidence that objects and groups of objects do not display the same warping effects and thus are not perceptually the same.

REFERENCES

Andrea M., Cathy P., Karl F., Alumit I. (2004). Where Bottom-up Meets Top-down: Neuronal Interactions during Perception and Imagery, Cerebral Cortex, Volume 14, Issue 11, November 2004, Pages 1256–1265, https://doi.org/10.1093/cercor/bhh087

Anton-Erxleben, K., Henrich, C., & Treue, S. (2007). Attention changes perceived size of moving visual patterns. Journal of Vision, 7(11), 5. https://doi.org/10.1167/7.11.5

Coren, S., & Girgus, J. S. (1980). Principles of Perceptual Organization and Spatial Distortion: The gestalt illusions. Journal of Experimental Psychology: Human Perception and Performance, 6(3), 404–412. https://doi.org/10.1037/0096-1523.6.3.404

Fisher, G. H. (1967). A common principle relating to the Muller-Lyer and Ponzo Illusions. The American Journal of Psychology, 80(4), 626. https://doi.org/10.2307/1421197

Gobell, J., & Carrasco, M. (2005). Attention alters the appearance of spatial frequency and gap size. Psychological Science, 16(8), 644-651. doi:10.1111/j.1467-9280.2005.01588.x

He, L., Zhang, J., Zhou, T., & Chen, L. (2009). Connectedness affects Dot numerosity judgment: Implications for configural processing. Psychonomic Bulletin & Review, 16(3), 509–517. https://doi.org/10.3758/pbr.16.3.509

Kestenbaum, R., Termine, N., & Spelke, E. S. (1987). Perception of objects and object boundaries by 3-month-old infants. British Journal of Developmental Psychology, 5(4), 367–383. https://doi.org/10.1111/j.2044-835x.1987.tb01073.x

Makovski, T. (2017). The open-object illusion: Size perception is greatly influenced by object boundaries. Attention, Perception, & Psychophysics, 79(5), 1282–1289. https://doi.org/10.3758/s13414-017-1326-5

Palmer, S., Rock, I. Rethinking perceptual organization: The role of uniform connectedness. Psychonomic Bulletin & Review 1, 29–55 (1994). https://doi.org/10.3758/BF03200760

Peterson, M.A. The proper placement of uniform connectedness. *Psychon Bull Rev* 1, 509–514 (1994). https://doi.org/10.3758/BF03210956

Quinlan, P. T., & Wilton, R. N. (1998). Grouping by proximity or similarity? competition between the gestalt principles in Vision. Perception, 27(4), 417–430. https://doi.org/10.1068/p270417

Titchener E.B., 1901. Experimental Psychology: A Manual of Laboratory Practice, Volume I, London: MacMillan.

Todorovic, D. (2008). Gestalt principles. Scholarpedia, 3(12), 5345. https://doi.org/10.4249/scholarpedia.5345

Vickery, T. J., & Chun, M. M. (2010). Object-based warping. Psychological Science, 21(12), 1759-1764. doi:10.1177/0956797610388046

Wackermann, J. (2017). The oppel–kundt Illusion. Oxford Scholarship Online. doi:10.1093/acprof:oso/9780199794607.003.0035

Yousif, S., & Scholl, B. (2017). The ONE-IS-MORE ILLUSION: Sets of discrete objects
appear less extended than equivalent continuous entities in both space and time. Journal
of Vision, 17(10), 1387. doi:10.1167/17.10.1387