STIMULUS ADAPTATION ON PERCEPTUAL ERROR IN EBBINGHAUS ILLUSION

SEEING IS DECEIVING:

THE EFFECTS OF STIMULUS ADAPTATION ON PERCEPTUAL ERROR IN THE EBBINGHAUS ILLUSION

By

COURTNEY G. KERSTEN, Hon. B. Kin.

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AUTHOR: Courtney G. Kersten, Hon. B. Kin. (McMaster University)

SUPERVISOR: James Lyons, Ph.D.

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ABSTRACT

Although visual illusions have been used extensively to explore the mechanisms subserving perception and action, controversy exists regarding the extent to which illusions may differentially affect the perceptual and motor systems. In part, this is because it is often difficult to accurately assess the perceptual influence of illusory stimuli since participants are usually asked only to report binary size decisions (bigger or smaller) of an illusory stimulus relative to a control figure. Questions of relative size or the direction of misperception remain unanswered. In this thesis, 10 experiments, comprising eight separate studies, were conducted to address these issues. In Experiment 1, a software tool was developed that allowed participants to size-match a target to a Control figure (Experiment 1a), as well as both the Large (Experiment 1b) and Small Annuli (Experiment 1c) Ebbinghaus Illusion stimuli. These experiments provided an accurate percentage of misperception score when each of the three conditions was presented in isolation. Results from Experiment 2, however, suggest that when each of the three conditions are presented in a random and repeated stimulus array, a degree of perceptual adaptation occurs in which illusory effects are biased in the direction of the large annuli stimulus. Experiments 3-8 provided evidence to suggest that the degree of motor involvement (Experiment 3), number of illusory stimuli present (Experiments 4 and 5), direction of attention (Experiment 6) and visual field laterality (Experiments 7 and 8) have minimal influence on the adaptation effects observed in Experiment 2.

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I was once told that "A LIFE" should not be simply judged by the things one achieves, one possesses, or the by the people one has met, but rather a LIFE should be judged by the people one has come to love, cherish, and appreciate.

"The act of 'seeing' seems so effortless that it is difficult to appreciate the vastly sophisticated and poorly understood machinery that underlies the process. Illusions, often, are those stimuli that exist at the extremes of what our system has evolved to handle. Sometimes illusions stem from assumptions made by the visual system; at other times they represent an active recalibration. In all these cases, illusions serve as a powerful window into the neurobiology of vision, and have pointed towards new experimental techniques".

- D. M. Eagleman

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PREAMBLE

The research presented in this thesis investigated the degree to which stimulus adaptation mediates perceptual error in the Ebbinghaus illusion. This thesis consists of 8 Experiments, with the Experiment 1 composed of 3 separately run protocols (A,B,C). Each Experiment has a separate introduction, methods, results, discussion, and conclusion sections, followed by appropriate tables and figures. Experiment 1, investigated perceptual error under both Ebbinghaus Illusionary conditions and a non-illusionary condition when each was presented in isolation and within a predictable environment. Experiment 2 investigated how perceptual error is mediated when the same illusionary stimuli were combined within a random and unpredictable environment. The results of Experiment 2 support the existence of adaptation effects between and within illusionary stimuli demonstrating a hysteretic shift that is biased by the Large Annuli illusionary condition. Experiments 3-8, each focus upon specific methodological issues within Experiment 2 and seek to control for specific variables that may have confounded the results in Experiment 2. Experiment 3 investigated the motor influence of slider manipulations found within Experiment 2. Experiment 4 and Experiment 5 further investigated the hysteretic shift in adaptation effects when only one illusionary condition was present within the control condition. Experiment 6 addressed the confounding starting size variable within Experiment 2 whereas Experiment 7 and Experiment 8 addressed laterality issues of stimulus influences. A general introductory section precedes all 8 experiments, with a general discussion and conclusion summarizing the scientific contributions of this thesis.

GENERAL INTRODUCTION

It has been long established in the motor behaviour literature that prior events can have a significant influence on subsequent movements. The Inhibition of Return phenomenon (e.g., Welsh & Pratt, 2006), range effects (e.g., Poulton, 1974), and changes in the trajectory characteristics of aiming movements depending upon the success or failure outcomes of previous trials (e.g., Elliott, Hansen, Mendoza, & Tremblay, 2004) are but only three examples of goal directed actions being reliably mediated by previous response parameters. Whereas each of these situations considers both the temporal and spatial characteristics of previous environmental events upon subsequent action, one area that has received less attention in the motor behaviour literature has been the ways in which perceptions of identical stimuli may change across the course of time. This idea, that object perception is a dynamic, even creative process, has been well established in the philosophy and psychology literatures for the better part of 200 years, but is rarely considered in the motor control domain.

The earliest thinking in this regard was influenced by the British empirical philosophers John Locke and George Berkeley. They viewed perception as an atomistic process, in which sensory elements (colour, shape, and brightness) were pulled together, component by component, in an additive fashion (see Kandel, Schwartz, & Jessell, 2000 for a review). German Gestalt Psychologists Max Wertheimer, Kurt Koffka, and Wolfgang Kohler, saw perception, not as atomistic, but rather as holistic, emphasized a more modern view of this idea in the early 20th century. This school of thought saw visual perception as an active and creative process. Where the brain collected the information provided to the retina and creating a form that was simply more then just the sum of its elements. Their idea was that object perception depended on, the physical properties of that object, as well as depended on the contextual interactions active within the objects. In other words, how we as humans perceive any visual object at any given time depends on the attributes of other features present in the same image. Kandel, Schwartz, and, Jessell (2000) stated that recognizing a musical melody is an analogue often used by Gestalt psychologists in explaining the perceptual interpretation of visual form. Gestalt psychologists suggest that what is being recognized within a melody is based on two things: the sequence and the interrelationship between notes. As such, a melody that is played in different keys or at different tempos will still be recognized accordingly as long as the relationship of the notes remains. Whereas this analogy demonstrates the importance and dependence on the interrelationship between auditory stimuli, visual perception from the Gestalt perceptive has this similar interrelational property wherein the physical sizes of objects in the visual field can change but, as long as the interrelationship between objects is maintained, the object will be recognized correspondingly. One such specific visual situation in which this interrelationship is strongly demonstrated is with respect to the perception (and misperception) of visual illusions.

The human perceptual system encounters hundreds of visual illusions in a lifetime. These illusions occur most often when observing specific objects within a preset context or under unique viewing conditions. According to Kandel, Schwartz, and Jessell (2000) visual Illusions are 'misreadings' of visual information by the brain and it is by investigating these misreadings, that concepts and illustrations of how the brain applies certain assumptions from the perceptual world to the sensory information it receives has come to be discovered. In fact, as early as 1865, when Ernst Mach discovered the illusionary bands of bright and dark which separated the two distinct luminance areas (known as Mach bands), illusions have been researched with a main focus concentrated on understanding how we misperceive an object. The nature of visual illusions and whether they could potentially shed meaningful light on underlying sensory function has, however, been the subject of debate since these earliest investigations. Kulpe (1893, as cited in Eagleman, 2001), for example, saw perceptual illusions as "subjective perversions of the contents of objective perception" (p. 920). Regardless, perceptual illusions were very important to Gestalt principles and 40 years later Wertheimer redefined the importance of illusions in the development of neurobiological research. To the Gestalt psychologists, visual illusions demonstrate two very important things: That the mind does not always deliver an accurate interpretation of the perceptual inputs it receives and; that mind plays an active rather then passive role in representing perceptual inputs.

EARLY EBBINGHUAS STUDIES – EBBINGHAUS IN THE SOCIAL SETTING:

The illusion of particular interest to this thesis is the Ebbinghaus/ Titchener circles Illusion [1]. The Ebbinghaus Illusion is titled a size-contrast illusion, in which a target circle surrounded by many smaller circular annuli is judged to be perceptually larger in comparison to a target circle of the same size surrounded by several larger circular annuli (van Donkelaar, 1999).

As noted earlier, Gestaltists saw visual illusions working perceptually on the basis and/or dependence of the interrelationship principle of perceptual organization. The question then becomes, what other attributes could change amongst the objects in the visual field that would mediate the illusionary effect? Ostrom (1983), for example, suggests that social knowledge could potentially affect judgments that do not really have an outright inherently social nature. Current research in this regard has suggested that size-contrast effects may be dependent, upon three things: The first is that size contrast effects may be

[1] Controversy has recently surfaced with respect to the authorship of the surrounded circles illusion, commonly referred to as the Ebbinghaus/Titchener illusion (e.g., Coren, 1971; Muise, Brun, & Porelle, 1997; Weintraub & Schneck, 1986) Referring to the illusion with both names suggests that the illusion was: 1) was discovered by Ebbinghaus and Titchener concurrently, and 2) the authorship of this illusion is still unresolved. Burton (2001) reviews contemporary sources which suggest that in the 1890s Ebbinghaus originally introduced this illusion, but not in a publication. He argues that there is no evidence that Titchener publicly claimed the rights of this illusion and in fact he suggests that Titchener referred to the illusion as “Ebbinghaus circles” in his 1898 book review (Burton, 2001). Burton also notes that origination of the surrounded circles illusions to Titchener did not appear until 1957. For these reasons, and for the sake of clarity, the surrounded circles illusion studied in this thesis will be referred to throughout as the Ebbinghaus Illusion.

dependent on the physical magnitude differences between target and context stimuli size. The second is that it maybe dependent upon the amount of attention that is delivered to a set of context stimuli in the same perceptual field as the target. And thirdly, size contrast effect maybe dependent upon any similarities that are created between the stimuli during presentations. For example, Coren and Miller (1974) used versions of the Ebbinghaus illusion and varied the context stimuli from the target stimulus to investigate such issues and suggest that the Ebbinghaus illusion is a function of the similarity between the inducing objects and the target.

Coren and Enns (1993) further developed this idea by showing that similar attentuation effects arose when the target and context stimuli were not only similar but also more meaningful. Overall then with respect to this study, stronger size-contrast effects have been shown when context and target stimuli belong to the same "real-life" categories. These studies thus demonstrate the importance of not only meaningful, but also physical similarity between target xand context stimuli for the magnitude of size-contrast effects.

More recently, Stapel and Koomen (1997) investigated how social knowledge can affect actual perceptions of physical magnitude. They suggested physical magnitudes of a stimulus are perceived in a relative way (i.e., where the surrounding contextual stimuli have a significant effect on the perceived magnitude of the target). In their experiment they used the Ebbinghaus illusion as their model to investigate this concept and demonstrated that the magnitude of the size-contrast effect was dependent to a large degree upon target context similarities, as well as, an association between target and context stimuli on social categorical dimensions. It was found that the size-contrast effect is stronger when social stimuli are physically similar than when they are look different but are from the same social stimuli category. As well, it was demonstrated that size-contrast effects will be stronger when all stimuli belong to the same social category then when the target and surrounding annuli belong to different social categories. (Stapel & Koomen, 1997).

A different, but somewhat related, idea regarding the Ebbinghaus Illusion is that the perception of combined stimuli will elicit interpretations that are not physically present when the combined components are perceived separately. Once again, this is based on the Gestalt principle that the whole differs from the sum of its individual parts. Research with the Ebbinghaus illusion has suggested that perception really does not reflect the physical world, where perceived size of an object, is really not interpreted to be the same as the physical size of the object (Gonzalez-Perez, 2006).

The more specific question as to *why* we perceive the whole as different from the sum of the parts has driven much of the recent research into the nature of perception relative to illusions and how we interact with them. This dissociation between "pure" perception and goal directed action is an important one and has formed the basis for extensive research investigating exactly how susceptible the brain may be to these visual "misreadings". One major focus of this research is to use visual illusions as a tool to investigate the underlying mechanisms that control perception and action. However, there still seems to be controversy regarding the conditions under which (and to what extent) visual illusions may differentially affect the human perceptual and motor systems. As a result, investigations employing illusory stimuli such as the Ponzo illusion, Muller- Lyer and the Ebbinghaus Illusions have become increasingly prevalent over the past 15 years. Although details vary among illusionary dimensions, most of these studies explore whether what we perceive of a given stimulus translates into motor actions directed toward that stimulus.

Aglioti, DeSouza, and Goodale (1995) explain that the previous work of Bridgeman, Kirch, and Sperling (1981) as well as that of Wong and Mack (1981), suggests that visual mechanisms that mediate visual control of actions have a tendency to work in egocentric coordinates. Whereas, visual mechanisms that mediate the perception of objects have a tendency to work in allocentric coordinates. Based on these studies, Aglioti, DeSouza, and Goodale (1995), for example, suggest that perception of the visual world is relative:

> *Visual perception seems to use a coordinate system that is world- based, in which objects are seen as changing location relative to a stable or constant world; the systems controlling actions can not afford these kinds of constancies and must compute the location of the object with the effector that is directed at the target.* (p. 680)

In other words, they suggest that we as humans make judgments most of the time in relative rather then absolute manner (Aglioti, DeSouza, & Goodale, 1995). In accordance with Aglioti, DeSouza, and Goodale (1995), Marotta et al. (1998), suggest that perceptual mechanisms work in a relative manner, where the interrelationship between objects in the array contribute to the overall scene interpretation. Marotta et al. (1998) suggest that it is, "Pictorial cues such as interposition, familiar size, and perspective, provide some of the most pertinent information about the nature of objects and their relations in the scene" (p. 491).

Numerous studies have shown that when under an optical illusion influence, specifically the Ebbinghaus Illusion, human perception of object size is at odds with the calculations generated by the human visuomotor system. Because the Ebbinghaus visual illusion has been shown to have a particularly power effect upon our perception of object size (Plodowski & Jackson, 2001), we have chosen this illusion as the basis for this study.

As noted, there have been numerous attempts to determine whether the visual awareness (perception) is related to motor behaviour (action). This relationship has been researched with respect to location (brain area) and process (visual pathways). With all of this research however, the Ebbinghaus illusion still remains at the center of an enormous debate in cross-modal research of visuomotor control. The controversy essentially involves whether or not vision for perception and vision for action have separate or combined neurological processing streams. As stated by Plodowski and Jackson (2001), "It is well know that visual illusions can have a dramatic effect upon visual perception of object size. It still remains the subject of much debate, however, whether visual illusions have a similar influence on visually guided actions" (p. 304).

Many studies have investigated the Ebbinghaus illusion and the associated perceptual and motor effects that it carries. One influential study in this regard was conducted by Goodale and Milner (1992) demonstrated that the Ebbinghaus illusion was effective in distorting the perception of target size, but only in a perceptual task. Specifically, no distortion was revealed when participant had to grasp the central disc of the illusion in their study. Their results suggest that what we perceive may in fact not be what essentially guides our motor behaviours and actions.

PERCEPTION-ACTION HYPOTHESIS:

Three years after this original work, Milner and Goodale (1995) suggested that the locus of this dissociation lies in separate visual pathways (distinguished by their origin and the path in which they continue on)[2] which are individually responsible for perception and action. Specifically, according to this perspective, Milner and Goodale proposed the perception versus action hypothesis that holds that the ventral stream is concerned primarily with the perception of the object. Where, on the other hand, the dorsal visual stream conversely is related to the

[2] It has been proposed that ventral stream originates in the area of V1, which then flows into the temporal lobe. It has also been suggested that the dorsal stream originates in the area of V1, but flows into the parietal cortex, instead of the temporal lobe where the ventral stream flows (Gerhard, 2006).

visual guidance of actions. One particular study (Goodale, Milner, Jakobson, & Carey, 1991) conducted with neurological patients who had damage to either the ventral or dorsal stream, supports this hypothesis. Goodale et al. (1991) showed that dissociations between perceptual and motor deficits arose within these neurological damaged patients.

Following this reasoning, it has been suggested that such visual Illusions could be potentially used as well as an excellent tool to reveal the distinction in the functional pathways in the normal brain. Specifically, it was suggested that using visual illusions to investigate the two visual pathways in the normal brain, would be an excellent way to show the dissociation between perception and action based on the their sensitivity to the context of a target (Pavani, Boscagli, Benevuit, Rabuffetti, & Farne 1999). Particularly strong evidence for this perception vs. action hypothesis is found in studies by Aglioti, DeSouza, and Goodale (1995), and Haffenden and Goodale (1998). In both of these studies, the Ebbinghaus size-contrast illusion was used to investigate grip size apertures. Even though, participants reported verbally that they perceived the disk, surrounded by the smaller circles (small annuli), to be larger, than the same size disc surrounded by larger circles (large annuli), they used equivalent size grip apertures when asked to physically grasp the disk. It was found that participants needed a difference of at least 2.5 mm between the diameters of the two discs for them to perceive the discs as identical in size[3]. It was revealed that all participants treated discs that were actually physically different in size as perceptually equivalent and they treated discs that were physically identical as perceptually different. Therefore, it was concluded from these results that the visual size-contrast illusion affected perception (ventral) to a much larger extent than grasping (dorsal) thereby supporting Milner and Goodale's original perception-action model.

More specifically, Aglioti, DeSouza, and Goodale (1995) suggested that the size judgment task employ the ventral stream (allocentric) and the grasping task could be associated respectively with using the dorsal stream (egocentric).

CONTRADICTING EVIDENCE FOR A P-A MODEL:

Numerous studies have acknowledged the Ebbinghaus illusionary discrepancy effects in perceptual and grasping tasks however much of this evidence is inherently inconsistent with Milner and Goodale's Perception-Action Dissociation Model. A study by Dursteler and Wurtz (1998), for example, looked at motion perception and smooth pursuit eye movements. It was found from this study that indeed there seemed to be a strong association between the visual input and motor output. As well, Pavani, et al. (1999) found that the Ebbinghaus Illusion similarly influenced perceptual estimation and hand shaping while

[3] It is suggested from these studies that quantifiable evidence from the characteristics of visual illusions is an important consideration in interpreting potentially conflicting results.

grasping. Therefore it seems plausible that perception and action may be intrinsically linked.

A more direct challenge to the Perception-Action model comes from Glover and Dixon (2002) who proposed that maximum grip aperture is not an appropriate way to measure the effect of an illusion in a grasping task. Rather, they investigated the trajectory of the reaching movement itself to the Ebbinghaus illusion and found that the illusionary size decreased as the trajectory progressed. Of primary importance was the finding that there was a significant illusory effect in the planning phase of the movement with this effect decreasing during the online control (correction) phase of the overall movement. This is an important result since it is during this online control phase where maximum grip aperture was collected in Aglioti et al.'s (1995) study thereby creating a potential confound between the two variables.

Several other lines of evidence seem inconsistent with the Perception-Action model. One of these comes from a study conducted by Franz, Bulthoff, and Fahle (2003), the results of which suggest that the Ebbinghaus Illusion affects grasping to the same extent as perception. Franz et al. (2003) interpret this evidence to suggest that the same signals are responsible for both the perceptual and motor effects, as was evident in interactions with the Ebbinghaus Illusion. In addition, Handlovsky, Hansen, Lee, and Elliott (2004), examined how the Ebbinghaus illusion affects the planning and control of discrete aiming movements. They found that when introducing and removing the Ebbinghaus

Illusion during the movement planning or movement execution, changes occurred in the planning and control of discrete aiming movements. In this study, it was found that faster movement times were made to targets that appeared perceptually larger following movement initiation. These results demonstrate that the Ebbinghaus illusion affected aiming movements and therefore, were found to be inconsistent with the perception versus action dissociation theory proposed by Milner and Goodale (1995).

RECONCILING THE CONFLICTING EVIDENCE:

Van Donkelaar (1999) compared the perceptual versus action theories and suggested that the seemingly contradictory evidence might exist due to the choices of motor tasks used. He suggests, based upon work by Jeannerod (1984) showing that grip aperture is tightly linked to the physical characteristics of the object to be grasped, that when grasping movements are employed in these types of tasks the absolute (rather then the relative) attributes are of the utmost importance to task success. Consequently, given the relative nature of illusory biases, visual illusions can be expected to have very little effect.

As a way to further investigate these contradictory findings, van Donkelaar (1999) tested whether aiming movements would be affected by the Ebbinghaus Illusion in the same way that it has been found to have an influence on grip aperture. van Donkelaar (1999) found that movement times directed to the perceptually smaller target circles were significantly longer than when they were directed to perceptually larger target circles (i.e., exactly what Fitts' Law (1954) would predict for a physically smaller target). This evidence supports the contention that the relative size of the target, rather than its absolute size, is the primary mitigating influence on the control and execution of aiming movements. It is important to note that van Donkelaar's (1999) findings contradict evidence concerning grasping movement made under the same conditions thereby, suggesting that aiming responses are more directly influenced by visual perceptual processing than motorically more complex grasping responses.

These findings suggest that although the Ebbinghaus Illusion has been shown to influence visually guided motor actions in certain conditions, it is difficult to ascertain the contribution of any specific process because of the different motor tasks employed in the experiments. Indeed, a closer look at the studies cited throughout the thesis to this point shows that, not only are different motor tasks used in these experiments, but also different measures of perceptual influence are employed. Further illustrating the importance of task choice and perceptual measure, Franz (2003) noted that studies where perceptual effects were reported to be larger then motor effects employ what are essentially different perceptual measures. Specifically, Franz (2003) found that when comparing traditional perceptual measures to manual estimates, inconsistent results for the perceptual effects were revealed. Furthermore, he found that if the data are normalized the corrected perceptual illusion effect corresponded with the illusion effect found in grasping. Overall, Franz suggests that because there are systematic deviations between manual estimation and the traditional perceptual measures (specifically that the manual estimation shows larger slope in relation to physical size than traditional measures) a correction for slopes must always occur if comparisons between these different tasks are performed. This would further suggest that the same neuronal signals are responsible for the illusion regardless of the measure employed (see also Pavani et al. 1999). Given these results, it is not unreasonable to assume that different perceptual measures could differentially affect the results of any particular experiment thereby, resulting in inconsistent, even false assumptions. This issue demonstrates a need for a universally acceptable perceptual measure that, ideally, is also quantifiable.

QUANTIFICATION OF PERCEPTUAL BIAS:

In one of the few studies to date that attempts to quantify the size of perceptual error associated with the Ebbinghaus illusion, Pavani et al. (1999) had participants perform perceptual estimations and grasp tasks using three different Ebbinghaus illusion conditions (Neutral, Large Annuli, Small Annuli). Results showed that, overall, participants were: a) accurate at estimating target disc size in the neutral condition; b) disc size was overestimated by approximately 0.2 mm when it was surrounded by the small annuli array and, c) was underestimated by approximately 0.5 mm when it was surrounded by large annuli array. Although these quantification procedures are an important first step (for example, they provide one of the first indications that the magnitude of the illusory effect may be different for each of the two Ebbinghaus conditions), there are several issues that were not addressed in this study. For example, there is no information as to how the actual perceptual measure adjustments were controlled and by whom[4]. As well, the perceptual measure was fundamentally different from the measure used to evaluate the effect of the illusion on action.

Franz, Bulthoff, and Fahle (2003) solved this problem to some degree by employing a consistent perceptual measure when comparing to both aiming and grasping motor actions. In their perceptual task participants adjusted an isolated comparator circle to match the size of the target disc in 4 separate Ebbinghaus configuration conditions (i.e., large-near, large-far, small-near, and small-far, where the large and small represented the surrounding annuli and the near and far represented the similar distances between the spatial gaps between the target circles and the surrounding annuli). The results of this study suggested that the Ebbinghaus Illusion effects on perception and on grasping are virtually identical. Two things remain unclear, however. Specifically, no description was given as to the manner in which participants adjusted the isolated targets nor was there a non-illusory control condition.

DISCRETE VS. CONTINUOUS MEASURE OF PERCEPTUAL BIAS:

In the past, it has been often difficult to accurately assess the perceptual influence of illusory stimuli, since participants are usually asked to only report binary size decisions (bigger or smaller, etc.) regarding an illusory stimulus

[4] This is an important point since any effort to isolate "purely" perceptual measures must take into account the degree of motor involvement in any overt response made by the participant.

relative to a control figure. Due to the fact that visual illusions can provide us with important insight into the underlying mechanisms that control perception and action, it is important for researchers to be able to quantify the illusion's perceptual effect before further investigating additional avenues. In quantifying the illusion's perceptual effect systematic parametric analyses can be used to further address such questions. Quantification of the perceptual effect can be done by investigating all the possible physical characteristics (such as target size, annuli size, spatial distance between target and surrounding annuli, etc.) that contribute to the strength of that illusion's perceptual effect. This is a critical step in assessing the theoretically separate contributions of ventral and dorsal stream processing on aiming and grasping. Using specific set characteristics of an illusion, there is a need to develop a measure that will accurately deliver a perceptual effect of the Ebbinghaus Illusion's influence on human visuomotor abilities.

As noted earlier, the Ebbinghaus Illusion is titled a size-contrast illusion, in which a target circle surrounded by many smaller circular anuuli is judged to be perceptually larger in comparison to a target circle of the same size surrounded by several larger circular annuli (van Donkelaar, 1999). Even though this definition describes the Ebbinghaus Illusion correctly, it demonstrates the lack of physical characteristic measurements required of the illusion. A better definition is necessary to:

1) Outline basic physical characteristics of the illusion (i.e. target size, annuli size, etc.)
2) Distinguish the perceptual effect of the illusion (quantifying perceptual illusion effect)
3) Distinguish the perceptual effects and their influences on motor actions (both aiming and grasping)

Such an approach would afford the opportunity to answer several important questions: 1) Is it possible to quantify (mathematically) the perceptual influence/perceived effect of the Ebbinghaus Illusion using a more accurate perceptual measure ?; 2) Is it possible to use the same measure to compare the perceptual influence and action influence of the Ebbinghaus Illusion? and; 3) Is it possible to further explore the dissociation between perception and action on the basis of these results?

From the review thus far of perceptual measures employed, it seems that there is a need for a universal perceptual measure which can be used to accurately quantify the Ebbinghaus Illusion. In this study, the methodological design seeks to address and compensate for the previous confounding issues. The first issue relates to the restricted binary task that Aglioti, Desouza, and Goodale (1995) employed and were later criticized for. The perceptual measure design in this thesis allows participants to individually manipulate and adjust target sizes. It is believed that this design will allow for a more reliable and consistent measure of perceptual effect.

The second design issue that this study addresses relates to the need to use isolated targets as the manipulated stimuli. This issue arises from Aglioti, Desouza, and Goodale (1995) who were criticized for requiring participants to attend to and compare two separate visual objects, each embedded within a different illusionary background. Therefore, the perceptual measure employed in the following studies has participants attend to and compare two visually central circular images, with only one of those objects embedded within an Ebbinghaus Illusion configuration. It must be acknowledged that Franz, Gegenfurtner, Bullthoff, and Fahle (2000) demonstrated that the perceptual effects of the illusion was smaller when only half of the traditional illusion is judged. Also, it was important for them to note that when the perceptual effects of illusionary halves were summed, they were found to be less then when the illusion was presented and corresponding judged in its entirety. Therefore, this research then has shown that the illusionary effects may not be as strong, however, when investigating the perceptual effects of half of the traditional illusion, it could be suggested that this effect is actually a closer representation to evaluating grasping, aiming and reaching perceptual effects. Addressing such issues of whether absolute or relative interferences are the influencing factor, our perceptual measure is more compatible to aiming and grasping issues with this isolated comparator circle under no illusionary influenced.

Recently, Franz, Scharnowski, and Gegenfurtner (2005) suggested that research has been flawed in the past. They claim that certain stimuli used in prior experiments have been designed to reduce the chance of error specifically in the grasping tasks. The design of the experiments were such that the small and large annuli conditions were presented in isolation, which resulted in a non-illusionary effect because half of the illusion (and essentially the central target of the second half) could not act as a reference and therefore distort the illusion. This led Franz et al. (2005) to conclude that both the action and perception systems were susceptible to the Ebbinghaus Illusion. However, it could be suggested that when making comparisons requiring participants to attend to and compare two separate visual objects, each embedded within a different illusionary background as in Aglioti et al.'s (1995) study, gap distance between the central target and surrounding annuli could be used to compare size thereby resulting in a false manipulation and an inaccurate representation of the illusion's perceptual effect. This is an important consideration with respect to the proposed method of quantification, however again evaluating the perceptual effect in half of the traditional illusion is actually a closer representation to evaluating grasping, aiming and reaching perceptual effects.

Adding strength to this proposed perceptual measure, the gap equivalency between the central target edge and the edge of the surrounding annuli was maintained in both the small and large Ebbinghaus Illusion arrays similar to Haffenden, Schiff, and Goodale (2001). The small and large arrays employed in this new proposed perceptual measure, maintain gap distance between the edge of the surrounding annuli and the edge of the central target, as well the gaps between the edges of each surrounding annuli, in both the large and small circular arrays. However, unlike Haffenden, Schiff, and Goodale (2001) who increased the number of small annuli surrounding the target in the traditional Ebbinghaus, this new proposed perceptual measure maintained the traditional 11 small circles in the small annuli array. Maintaining the 11 small circles in the small annuli condition strengthens the proposed protocol, as the results from this study can be compared to other studies that employ the same 11 surrounding annuli (Agliot, DeSouza, & Goodale, 1995; Hanisch, & Konczak, 2001; Marotta, Desouza, Haffenden, & Goodale, 1998; Plodowski & Jackson, 2001; and van Donkelaar, 1999). When Haffenden, Schiff, and Goodale (2001) increased the number of annuli surrounding the target to investigate gap distances within the illusionary constructs, they technically changed the traditional Ebbinghaus Illusion which in turn could have influenced their results in numerous and indistinguishable ways.

The new perceptual measure employs an additional single isolated target comparator condition incorporated into the design. This isolated target comparator has been designed to measure actual perceptual errors under non-illusionary conditions. The nature of this isolation thus reduces the contextual measures employed previously in the theoretically neutral conditions by Pavani et al. (1999), or lack thereof (Franz, Bulthoff, & Fahle, 2003).

OBJECT PERCEPTION AND STIMULUS ADAPTATION:

Whereas the proposed methodological changes outlined above are important in and of themselves, perhaps the most significant contribution of the current work addresses the nature of object perception as envisioned by the early Gestaltists and largely ignored in the research described throughout this introduction. That is: Do participants perceive any given object at any given time in a way that is functionally independent of the attributes of other features present in the same image? In other words, are perceptual biases associated with repeated exposure of the same stimulus the same as those when the stimulus is combined with others in an unpredictable stimulus array? There is evidence to suggest not.

ADAPTATION LEVEL THEORY:

There is reason to believe that illusionary effects will differ when stimuli are presented in combination as opposed to being presented individually and within their own isolated environments. Helson (1947) proposed a theory centered on the assumption that effects of stimulation form a spatiotemporal configuration, which is heavily influenced by stimulation order. He proposed a situation in which for every excitation-response configuration that is present in a given stimulus array, there is an *assumed* stimulus which represents the pooled effects of all the previously presented stimuli. It is this point of pooling to which the organism can become attuned or adapted. Helson (1947) suggests that for every stimulation moment there is an adaptation level that is vulnerable and can change with time and with varying stimulus conditions. He suggests that even though average values of stimulus-configurations are important for response analysis, these values alone provide little quantification in specific situations that confront the organism. As well, Helson (1964) acknowledged the characteristic role of contextual factors as demonstrated by the adaptation level theory. He stated that if contextual factors presented to an individual are allowed to vary, adaptation effects should be more evident then when they are not allowed to vary within the experience of the individual then. Therefore, if an individual is exposed to repeated and random presentations of multiple stimulus events, an adaptation will develop wherein participants will generate an internal representation of a novel stimulus that takes on all the characteristics of all the stimuli events presented in the array.

Thus, Adaptation Level Theory raises two issues that are extremely relevant: Potential dependence upon previously similar presented stimuli and; Potential dependence upon combined illusory stimulus environments where any one, or combination, of illusionary stimuli mediate the illusory effects of an individual illusory condition.

PURPOSE:

A review of the existing research suggests that many studies can only infer perceptual effects of the Ebbinghaus Illusion. It is believed that the protocols employed in this thesis, fill a critical gap in the current literature by developing an accurate and more precise measure of both standard perceptual errors and perceptual errors due to Ebbinghaus Illusionary influence.

The purpose of this thesis, therefore, was twofold: The first purpose was to develop a method with which to objectively quantify the magnitude of the Ebbinghaus Illusion. The second purpose was to explore and assess any adaptation effects that may be present in the perception of the Ebbinghaus Illusion. Specifically, these studies seek to address issues of dependency upon past histories of perceptual interactions within illusory environments on observed illusory effects. As well, we sought to compare perceptual size and direction of the magnitude of end misperceptions (perceptual error) under both Ebbinghaus Illusory conditions (i.e. under and over misperception estimation effects). Thus, this thesis is comprised of eight individual experiments with experiment 1 additionally comprised of 3 individual protocols.

EXPERIMENT 1A: ISOLATED CONTROL CONDITION

1.0 Introduction

Taking the criticisms and suggestions from past research into consideration, the purpose of Experiment 1 was to develop a methodology to objectively quantify perceptual error under both Ebbinghaus illusionary Conditions and a non-illusionary condition in repeated but predictable environments. Specifically, in order to be able to accurately assess the perceptual influence of illusory stimuli that are presented repeatedly and randomly within a stimulus array, it is first necessary to obtain an accurate measure of perceptual error in a size-match task in which no illusory stimuli is present. The purpose of this initial study was, therefore, to obtain a reliable baseline measure of task performance against which those measures of accuracy obtained in the following studies (i.e., illusory conditions) can be compared.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 22.19 years) with normal or corrected- to- normal vision participated in the experiment. All participants used their right hand when making physical manipulations and all were naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The computer program used to develop the experimental protocols was Macromedia Flash™. The desired Ebbinghaus Illusion Configurations (i.e., the isolated right and left circular targets, as well as both the vertical and horizontal sliders) were presented on a computer monitor located approximately 75 cm from the participant.

In all experiments, each participant sat in a chair (55 cm tall) facing the monitor, the screen of which was 32.5 cm wide by 24.5 cm tall with a visual resolution of 1024 x 768 pixels (the overall resolution was 0.03125 cm/pixel). The monitor's angle was adjusted so that each participant, when sitting in front of the monitor, had a measurement of 76 cm from the bridge of their nose to both the top and bottom of the monitor allowing for an orientation of the screen perpendicular to the participant's gaze direction. A computer mouse was positioned on the desktop at both the midline of the computer monitor and participant 30 cm from the computer monitor. A keyboard was placed on a desk 45 degrees to the right of the participant at a distance of 50.5 cm to the enter button (see Figure 1a and 1b). Data for the perceptual task (physical ending sizes of manipulated isolated target circle expressed in pixels) were organized into printable charts based on the order in which the trials were presented to participants.

Procedure

The task involved participants manipulating the physical size of an isolated circle (target disc) on the right side of the computer monitor to perceptually match the physical size of an isolated circle (comparator target) on the left side of the computer monitor. This was accomplished by participants using either a horizontal or vertical slider that was presented on the computer monitor with the two target circles. The starting position of the slider for each trial was in the center of the computer monitor screen below, and centred between, the target circles (See Figure 2). On one half of the trials, participants used the horizontal slider and on the other half of the trials they used the vertical slider. These blocks were counterbalanced across participant. The horizontal slider was composed of a vertical bar that could be moved in left and right directions such that moving the slider to the right increased the size of the target whereas moving the slider to the left decreased the target size. The slider was controlled by the participant moving the computer mouse in the spatially compatible horizontal direction. The vertical slider was composed of a horizontal bar that could be moved up and down on the computer display. Moving the slider in an upward direction decreased the target size whereas moving the bar downward increased the size of the target. Again, the slider was controlled by the participant moving the computer mouse moving in the compatible vertical direction. The horizontal slider ran on a horizontal path 3.5 cm from the bottom of the screen, whereas the vertical slider ran on a vertical path starting at 6.5 cm from the bottom of the screen. The horizontal slider was 2.0 cm wide and 1.0 cm tall, and the vertical slider was 1.0 cm wide and 2.0 cm tall.

When the desired size of the target circle was achieved, the participant signaled the conclusion of the each trial by pressing the enter button on the keyboard. In order to control for participants simply replicating the amplitude of previous movements that they deemed successful, slider control was set to 5 different gain, or sensitivity, levels. The sensitivity levels were as follows: For every 1 pixilated movement on the slider: a 2 visual pixilated size increase appeared thus providing a gain ratio of 1:2 ratio. The other 5 sensitivities were 1:1.5, 1:1, 1: 0.75, 1:0.5, and 1:0.25. These sensitivity levels were randomized across all trials.

For all trials, regardless of starting size, the distance between the center of the left target and the center of the right target was 16 cm thus the center of each target was positioned at 8 cm on each side of the midline. The left target was 100 pixels in size (3 cm diameter) and remained this size throughout the experiment. Manipulations of the right target were achieved by either increasing or decreasing the diameter of the isolated right target from one of 6 designated starting sizes. Again to limit simple replication of previous movements, three designated "increasing" starting sizes of 25, 50, and 75 % of the size of the left central target (0.75 cm, 1.5 cm, and 2.25 cm respectively) and 3 "decreasing" starting sizes of 175, 150, and 125 % (5.25 cm, 4.5 cm, and 3.75 cm respectively) were employed (see Figure 2).

The experimental design was a 6 (starting size) by 2 (directions) by 5 (sensitivities) design. In total there were 6 different conditions and each condition was tested 10 times randomly for a total of 60 trials. All trials were presented to each participant in a completely random order produced by a real number generator run by Macromedia Flash™.

Experimental Design and Data Analysis

A 6 (starting size) x 2 (direction) x 5 (sensitivity) analysis of variance (ANOVA) was conducted on the perceptually judged physical manipulations. The dependent measure for the perceptually judged physical manipulations was the actual physical ending size of the right isolated target circle expressed in pixels. Multiple factor Main Effects and all interactions were further explored using Tukey's *HSD* procedure. In addition, and in order to determine the magnitude of size-match error, the final end size of the manipulated target disc (in pixels) was compared to the comparator target of 100 pixels.

Results

No main effects were present for starting size, direction of slider or sensitivity of slider. On average, all starting sizes overshot the designated 100 pixel target resulting a mean overshoot bias of 1.29 pixels (see Figure 3). There were no interactions.

Post Hoc Analysis to Comparator Value (100 pixels)

When the overall perceptual error of 1.29 pixels was compared against the comparator value of 100 pixels, it was confirmed that the overshoot in Experiment 1A was not significantly different from 100 (i.e., the size of the target).

Discussion

The lack of a significant difference from the 100 pixel target suggests that participants were able to accurately match two non-illusionary target circles in an isolated environment. The fact that no main effects for starting size, slider direction or slider sensitivity were revealed, suggests that these three methodological aspects, initially incorporated into the experimental design to act as controls, did not contribute to the slight but non-significant overshoot bias.

Overall, the results suggest that under conditions in which no illusionary influence is present, participants are able to accurately size match a control figure to a target.

Figure Captions: Experiment 1A

Figure 1a. Illustration of the experimental set up (aerial view).

Figure 1b. Illustration of the experimental set up (side view).

Figure 2. Illustration of the experimental condition employed in Experiment 1A (one increasing and one decreasing starting size under the control condition).

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the 100 pixel comparator target and the mean overshoot bias of 1.29 pixels.

Figure 1a

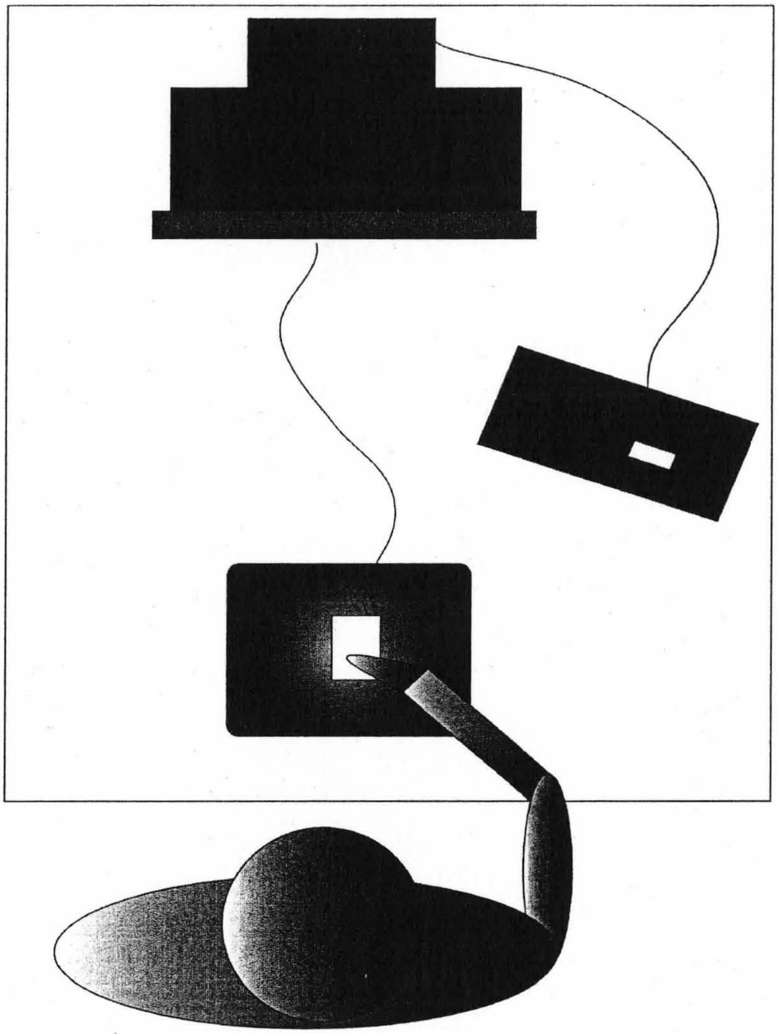


Figure 1b

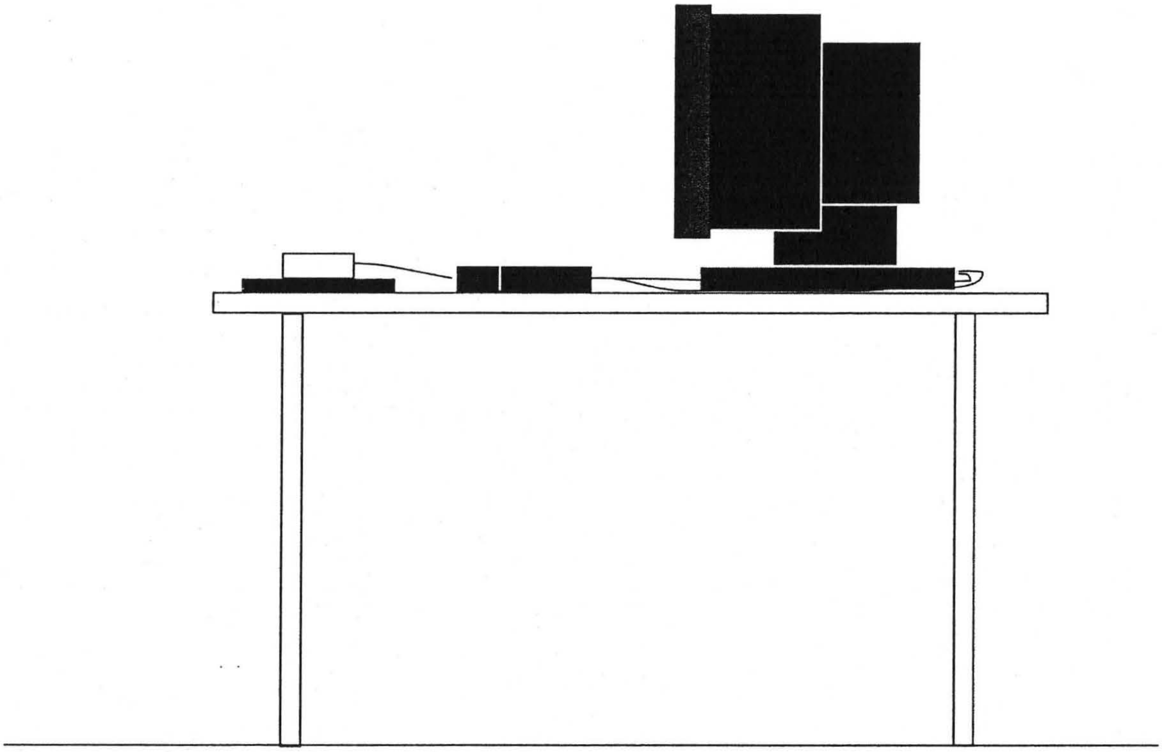


Figure 2

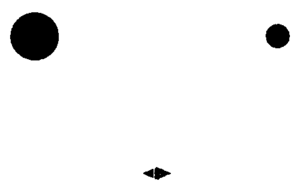
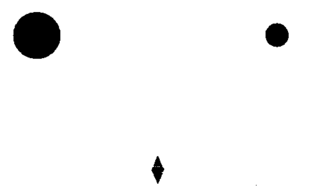
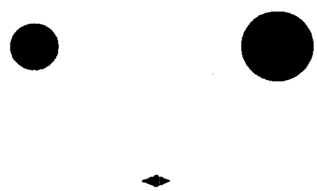
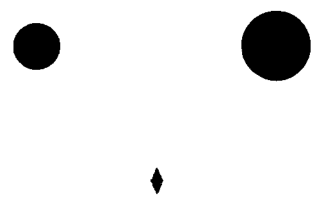
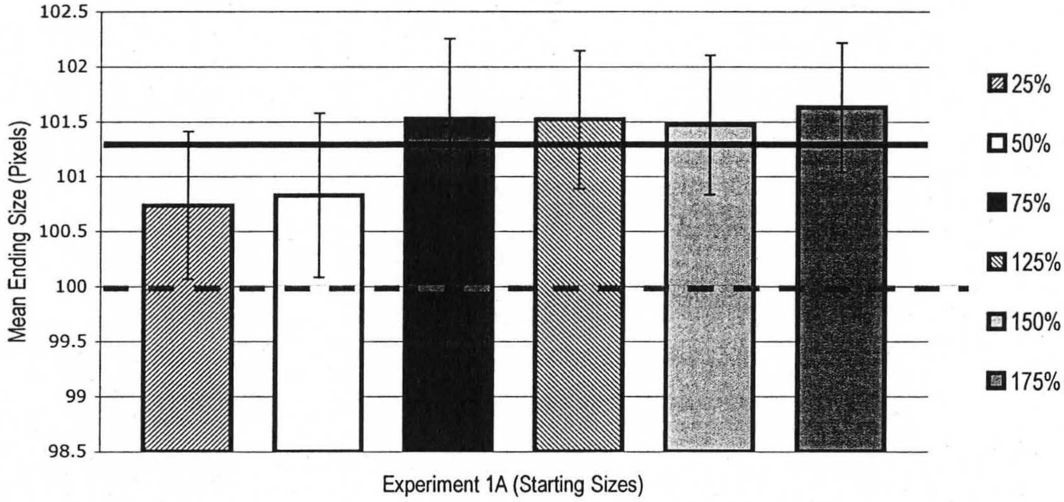
	Condition in Experiment One A	
	Left Isolated Target (100 pixels) / Adjusting Right Isolated Target	
Trials	*Horizontal Slider* *(Right Increase/ Left Decrease)*	*Vertical Slider* *(Down Increase/ Up Decrease)*
Increase *Right Target* *Starting Size =* *0.75 cm*		
Decrease *Right Target* *Starting Size =* *5.25 cm*		

Figure 3


102.5
102
101.5
101
100.5
100
99.5
99
98.5
Mean Ending Size (Pixels)
Experiment 1A (Starting Sizes)
25%
50%
75%
125%
150%
175%

EXPERIMENT 1B: ISOLATED LARGE ANNULI CONDITION

In order to be able to accurately assess the perceptual influence of illusory stimuli that are presented repeatedly and randomly within a stimulus array, it is also necessary to obtain an isolated measure of perceptual error in a size-match task in which only a Large Annuli (LA) illusory stimuli is present. The purpose of this study, therefore, was to obtain an isolated LA illusionary perceptual effect (anticipated undershoot bias) against which these measures of illusionary perceptual effects could then be compared to the previous measures of accuracy in Experiment 1 A.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 20.9 years) with normal or corrected- to- normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as was employed in Experiment 1A.

Procedure

The task was an exact replica of Experiment 1A, except that in Experiment 1B participants manipulated the physical size of an isolated circle (target disc) on the right side of the computer monitor to perceptually match the physical size of a target circle (comparator target) surrounded with 5 large circular annuli on the left side of the computer monitor (Large Annuli Condition). All other experimental design aspects of Experiment 1A were maintained.

For all trials, regardless of starting size, the distance between the center of the left target circle surrounded by the 5 large circular annuli and the center of the right isolated target was 16 cm, thus the center of each target was positioned at 8 cm on each side of the midline. The left target remained 100 pixels in size (3 cm diameter) and remained this size throughout the experiment. Manipulations of the right target were achieved by increasing or decreasing the diameter of the isolated right target from one of 6 designated starting sizes, exactly like experiment 1A. The left target was surrounded with 5 large circular annuli which were 5.5 cm in diameter. The 5 large circular annuli construct will be referred to as the Large Annuli (LA) Condition. The distances between the edges of the surrounding annuli and the edge of central target were 1.3 cm, and the gaps between each annulus were 1.0 cm (see Figure 1).

Experimental Design and Data Analysis

The experimental design was a 6 (starting size) by 2 (directions) by 5 (sensitivities) design In total there were 6 different conditions and each condition was tested 10 times randomly for a total of 60 trials. All trials were presented to each participant in a completely random order produced by a real number generator run by Macromedia Flash™.

Results

A main effect for Starting Size, F (5, 50) = 8.99; p.< 0.00001, was revealed with post hoc analysis confirming that all 3 increasing starting sizes were significantly different from all 3 decreasing starting sizes. On average, whereas all starting sizes significantly undershot the designated 100 pixel target, the increasing starting sizes produced a significantly greater underestimation than did the decreasing starting sizes (see Figure 2). The 3 increasing starting sizes were not significantly different from each other, nor were the 3 decreasing starting sizes different from each other. However, the mean of the 3 increasing starting sizes was significantly different from the mean of the 3 decreasing starting sizes (Average error on “increase” trials = - 4.1 pixels; average error on “decrease” trials = - 1.69 pixels). On average, the underestimation across all 6 starting sizes was 97.1 pixels.

As well, a main effect for Direction, F (1, 10) = 14.70; p.< 0.01, was evident with post hoc analysis confirming that perceptual underestimations using the horizontal slider (97.39 pixels) was significantly different from the underestimations when using the vertical slider (96.81 pixels) suggesting a more pronounced perceptual error under the vertical slider condition (see Figure 3). There were no interactions.

Post Hoc Analysis to Comparator Value (100 pixels)

When the perceptual error of in Experiment 1B of - 2.9 pixels was compared against the comparator value of 100 pixels, it was confirmed that the undershoot error observed in Experiment 1B was significantly different from 100.

When the mean target ending size under the horizontal slider of 97.4 pixels was compared against the value of 100 pixels, it was confirmed that the undershoot was not significantly different from 100. However, when the mean target ending size under the vertical slider of 96.81 pixels was compared against the value of 100 pixels, it was confirmed that the undershoot was significantly different from 100 (see Table 1).

Discussion

The significant difference from the 100 pixel target suggesting that participants were susceptible to the LA illusionary effect in the expected direction, thereby confirming and supporting the designed stimulus construct. Results of this experiment suggest that average human perceptual error under the LA illusionary influence was –2.9 %.

Again, no effect for Slider Sensitivity was present. However, main effects for Starting size and Slider Direction were evident. Slider direction demonstrated that when participants used the horizontal slider, they were more accurate than with the vertical slider. One possibility why this effect for slider direction was evident is that horizontal slider movements could reinforce gaze directions thereby strengthening the illusionary effect, and thus producing a stronger magnitude of perceptual error. This hypothesis is discussed in further detail in the general discussion section for Experiment 1 and Experiment 2

All starting sizes undershot the 100 pixel comparator target. This was expected and corresponds to the LA illusionary influence. When this result is examined in greater detail however, it is evident that participants reliably exhibited less undershoot error when they were required to decrease the size of the target disc than when they had to increase it. This effect for starting size was unexpected but its presence cannot be ignored. One possibility for this result may involve a range effect. This possibility, outlined briefly in the introduction, is discussed in greater detail in the general discussion section for Experiment 1. Overall, the results of Experiment 1B suggest that under conditions in which there is a LA illusionary influence, participants were unable to accurately size match to the comparator and consistently undershot the comparator target. This perceptual underestimation error occurs under conditions in which there is a LA illusionary influence and this error is significantly more pronounced when the target size has to be increased and when using the vertical slider. Therefore, further studies need to address starting size and slider direction influences on the misperceptions received by this protocol. These questions are dealt with in Experiments to follow.

Table 1.

Perceptual judgment errors by Slider Direction in Experiment 1B relative to the 100 pixel comparator target.

	Perceptual Judgment Errors in Slider Direction for Experiment 1B	
	Horizontal Slider (97.4 pixels)	Vertical Slider (96.81 pixels)
Comparator Target 100 pixels	=	≠
Experiment 1B Overall Perceptual Error (97.1 pixels)	=	=

Figure Captions: Experiment 1B

Figure 1. Illustration of the experimental condition employed in Experiment 1B (one increasing and one decreasing starting size under the LA condition).

Figure 2. Mean ending size (pixels) and standard error as a function of starting size against the 100 pixel comparator target and the mean undershoot bias of 2.9 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of slider direction against the mean undershoot bias of 2.9 pixels.

Figure 1

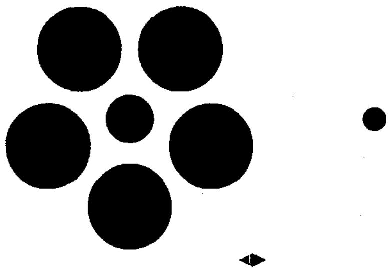
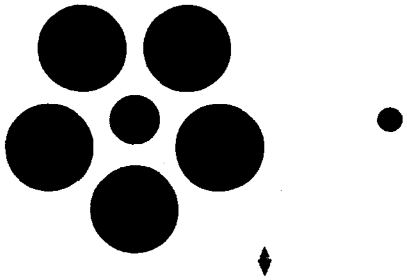
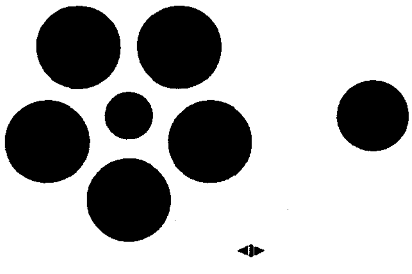
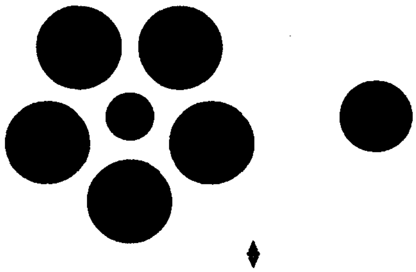
	Conditions in Experiment One B	
	Left Isolated Target (100 pixels) / Adjusting Right Isolated Target	
Trials	*Horizontal Slider* *(Right Increase/ Left Decrease)*	*Vertical Slider* *(Down Increase/ Up Decrease)*
Increase *Right Target* *Starting Size =* *0.75 cm*		
Decrease *Right Target* *Starting Size =* *5.25 cm*		

Figure 2

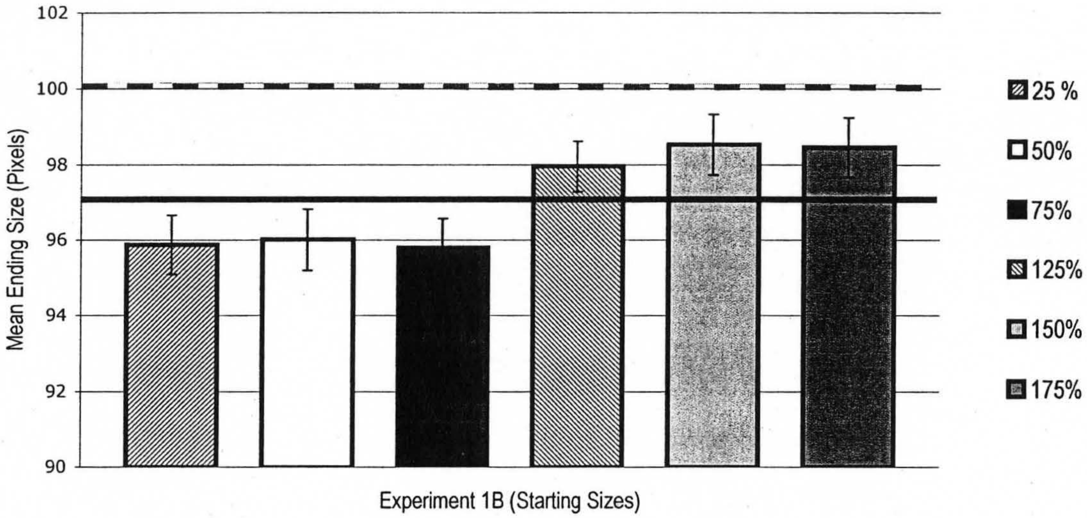
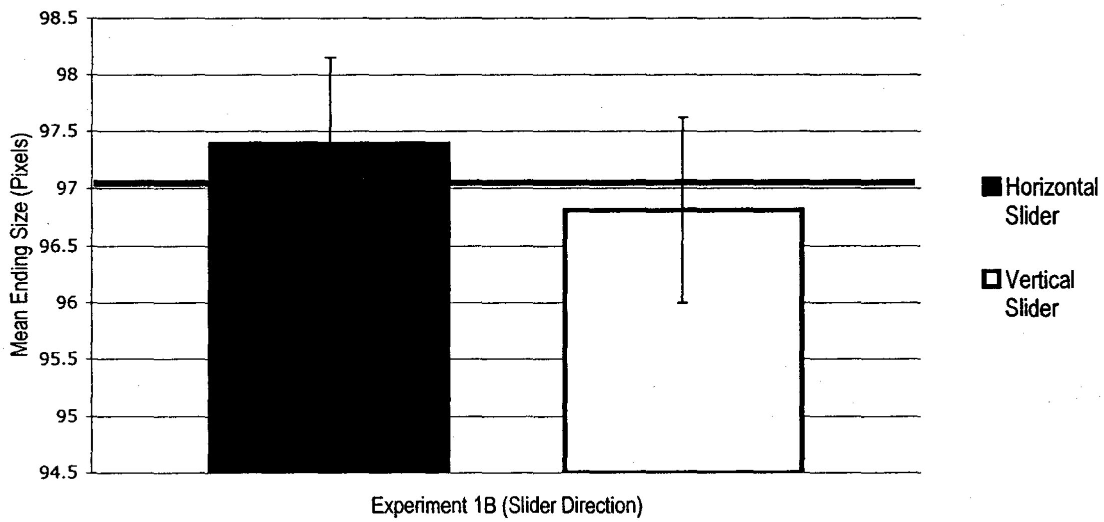

102
100
98
96
94
92
90
Mean Ending Size (Pixels)
Experiment 1B (Starting Sizes)
25 %
50%
75%
125%
150%
175%

Figure 3


98.5
98
97.5
97
96.5
96
95.5
95
94.5
Mean Ending Size (Pixels)
Horizontal Slider
Vertical Slider
Experiment 1B (Slider Direction)

EXPERIMENT 1C: ISOLATED SMALL ANNULI CONDITION

In Experiment 1B we sought to quantify the magnitude to the illusory effect in LA Ebbinghaus condition when it is presented in isolation. In Experiment 1C, we seek to do the same in the SA condition. The purpose of this study, therefore, was to obtain an isolated SA illusionary perceptual effect (anticipated by an overshoot bias) against which these measures of illusionary perceptual effects could then be compared to the previous measures of accuracy in Experiment 1A.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 19.5 years) with normal or corrected- to- normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as was employed in Experiment 1A.

Procedure

The task was an exact replica of Experiment 1A except, in Experiment 1C participants manipulated the physical size of an isolated circle (target disc) on the right side of the computer monitor to perceptually match the physical size of a target circle (comparator target) which was now surrounded with 11 small circular annuli on the left side of the computer monitor (Small Annuli Condition). All other methodological aspects of experiment 1A were maintained.

For all trials, regardless of starting size, the distance between the center of the left target circle surrounded by the 11 small circular annuli (1.0 cm in diameter) and the center of the right target was 16 cm, thus, the center of each target was positioned at 8 cm on each side of the midline. The left target remained 100 pixels in size (3 cm diameter) and remained this size throughout the experiment. Manipulations of the right target were achieved by increasing or decreasing the diameter of the isolated right target from one of 6 designated starting sizes as in Experiment 1A. The distances between the edges of the surrounding annuli and the edge of central target were 1.3 cm, and the gaps between each annulus were 1.0 cm (see Figure 1).

Experimental Design and Data Analysis

The experimental design and data analysis were identical to Experiment 1A.

Results

A main effect for Starting Size, F (5, 50) = 5.20; p.< 0.001, was evident with post hoc analysis confirming that significant differences exist between the decreasing starting size of 150 % and 175 % when compared to the increasing starting sizes of 25 % and 50 %. On average, all starting sizes overshot the designated 100 pixel target however the decreasing starting sizes produced a significantly greater overestimation than the increasing starting sizes. On average the overestimation across all 6 starting sizes was 104.62 pixels (see Figure 2).

On average, the 3 decreasing starting sizes were not significant different from each other, however, the 25 % and 50 % were significantly different from the 75 % increasing starting sizes. The mean misperception of the 3 increasing starting sizes was significantly different from the mean misperception of the 3 decreasing starting sizes (Average error on "increase" trials = 4.02 pixels; average error on "decrease" trials = 5.21 pixels) (see Figure 3).

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean perceptual error of 4.62 pixels was compared against the comparator value of 100 pixels, it was confirmed that this overshoot bias of 4.62% was significantly different from 100 (i.e., the target size).

Discussion

There was a significant difference from the 100 pixel target suggesting that participants fell under the SA illusionary effect again confirming and supporting the illusory effects of the stimuli. Results of this experiment suggest that average standard human perceptual error under the SA illusionary influence was + 4.62 %.

No effect for Slider Direction or Slider Sensitivity was present. All starting sizes overshot the 100 pixel comparator target which was expected and corresponds to the SA illusionary influence. However, once again the mean of the increasing and the mean of the decreasing starting sizes were significantly different from each other. Specifically, participants overshot the comparator target to a lesser degree when they were required to increase the size of the target disc than when they had to decrease the size of the target disc.

Overall, results suggest that under conditions in which there is a SA illusionary influence, participants are unable to accurately size match and again are susceptible to the illusionary effect. This misperception occurs independent of slider direction and slider sensitivity but is significantly more pronounced when starting sizes are larger.

Figure Captions: Experiment 1C

Figure 1. Illustration of the experimental condition employed in Experiment 1C (one increasing and one decreasing starting size under the SA condition).

Figure 2. Mean ending size (pixels) and standard error as a function of starting size against the 100 pixel comparator target and the mean overshoot bias of 4.62 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of the mean increasing and the mean decreasing starting size against the 100 pixel comparator target and the mean overshoot of 4.62 pixels.

Figure 1

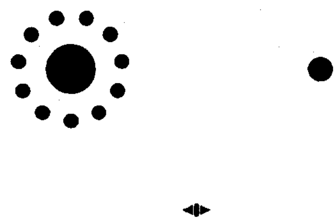
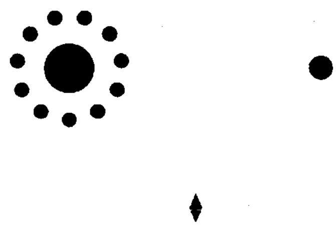
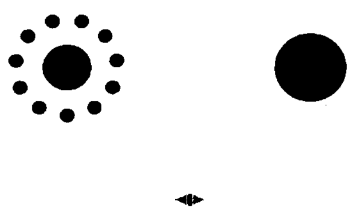
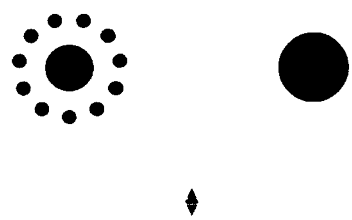
	Conditions in Experiment One C	
	Left Isolated Target (100 pixels) / Adjusting Right Isolated Target	
Trials	*Horizontal Slider* *(Right Increase/ Left Decrease)*	*Vertical Slider* *(Down Increase/ Up Decrease)*
Increase *Right Target* *Starting Size =* *0.75 cm*		
Decrease *Right Target* *Starting Size =* *5.25 cm*		

Figure 2

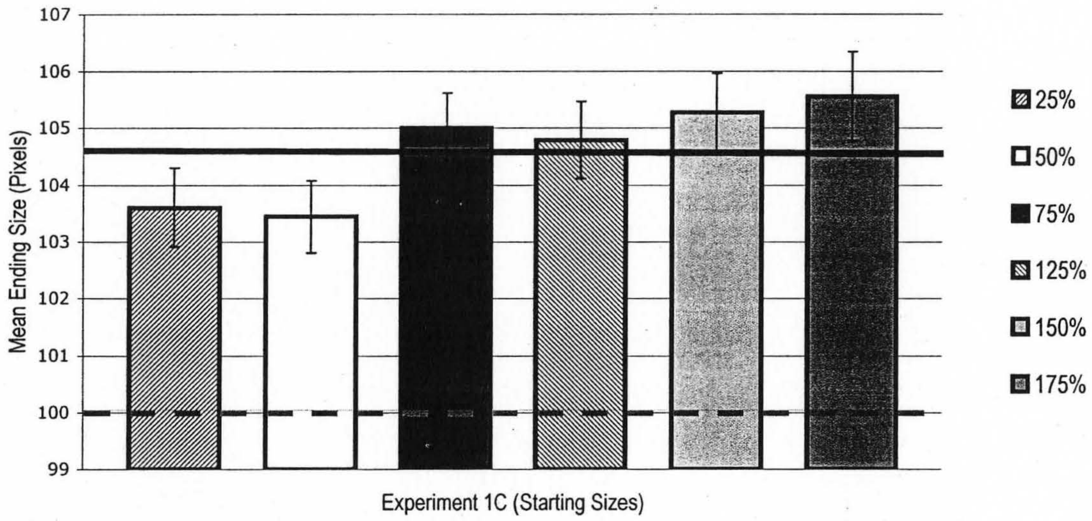
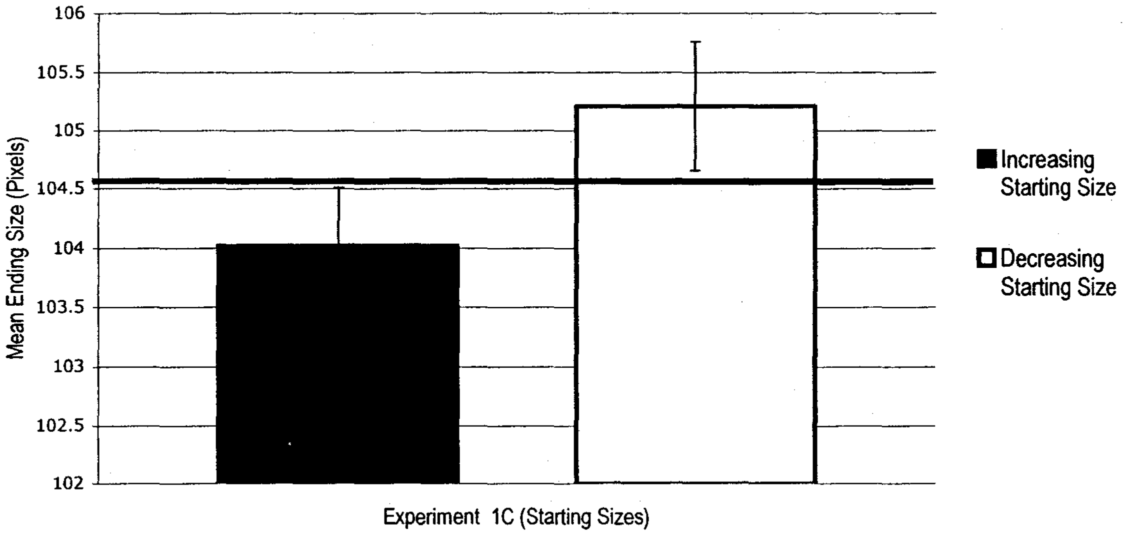

107
106
105
104
103
102
101
100
99
Mean Ending Size (Pixels)
Experiment 1C (Starting Sizes)
25%
50%
75%
125%
150%
175%

Figure 3


106
105.5
105
104.5
104
103.5
103
102.5
102
Mean Ending Size (Pixels)
Experiment 1C (Starting Sizes)
Increasing Starting Size
Decreasing Starting Size

EXPERIMENT 1A, 1B, AND 1C: ISOLATED CONDITIONS

Discussion

Franz, Scharnowski, and Gegenfurtner, (2005) have suggested that past research is somewhat flawed based upon the type of stimuli employed in the stimulus set. They suggest that this problem results from the fact that the SA and LA conditions were presented in isolation. When presented in isolation, they suggested that a non-illusionary effect would result (i.e., because half of the illusion was not present). Franz et al. (2005) suggested that the absence of the second part, essentially would reduce the overall illusory effect. However, Experiment 1 found perceptual effects in both illusionary conditions when only half of the illusion was presented, thus demonstrating that the surrounding stimuli in one half of the illusion is in fact sufficient to elicit a reliable effect (see Figure 1).

The consistent starting size effect could be explained by Range Theory (e.g., Parducci, 1965; 1968, Ostrom & Upshaw, 1968). This theory would suggest that when people assess a stimulus, they internally identify what they believe to be that stimulis greatest and least extreme values. From this internal assessment, they then create a range. This range then becomes the reference context that is based upon both, past experiences and/or the current context in which the current stimulus resides. Therefore, it has been suggested that any judgment of current stimuli within this range will be identified relative to where it exists within the present range (Parducci, 1965; 1968; and Ostrom & Upshaw, 1968).

In terms of specific motor behaviours (e.g. continuous tracking, size manipulations, aiming movements, etc.), Poulton (1974) suggests that range effects will exists wherein small amplitudes will be overestimated and larger amplitudes will be underestimated. For example, Bartz (1967) and Barnes and Gresty (1973) demonstrated that small target jump distances were overshot and larger target jump distances were undershot by the saccadic system. Based on these results, Poulton (1981) then suggested that the Range Effect was present in the saccadic system. More specifically, Kapoula (1985) demonstrate the range effect in the saccadic system, but also that the saccades could be made to overshoot or undershoot targets based on where the target was placed in the reference set. Thus, the experimental protocols in this thesis employed different starting sizes, as well as different illusionary conditions (which systematically resulted in participants overshooting or undershooting size manipulations), which may have generated these range effects. Specifically, when participants establish their point of origin for the target disc, those starting sizes that require the greatest manipulations (25% and 175%) will result in misperception of the comparator target to the greatest degree. Therefore, it would be expected on the basis of these range effects that the smallest starting size would underestimate and the largest starting size would overestimate the overall perceptual bias found in each experiment. Conversely, the results of the three studies that comprise

Experiment 1 suggest that there is a range effect present but only when compared against the mean perceptual bias resulting from the illusionary or non-illusionary stimuli. When compared against the 100 comparator target, the same pattern existed but was shifted accordingly to the illusionary or non-illusionary stimuli's presence (see Figure 2).

Slider sensitivity did not influence the results in any of these studies. However, main effects were found for both starting size and slider direction (which was initially designed as control variables in the protocol) suggesting further investigation is required as to their degree of influence. Further investigation into the influence of these two variables will strengthen the validity of the designed methodological protocols used in experiments 1A, 1B and 1C, and the results which suggest that the Control condition, the LA Ebbinghaus and the SA Ebbinghaus illusions were perceptually quantified in the expected directions.

Finally, it is important to note that although both the LA and SA illusionary effects were evident, the relative magnitudes of these effects were quite different. Specifically, the –2.9 % bias associated with the LA condition was less robust than the +4.62 % bias associated with the SA condition. As reported elsewhere (Aglioti, DeSouza,& Goodale,1995; Haffenden & Goodale,1998) it appears that the relative influence of the illusion depends to a great degree on whether the LA or SA Ebbinghaus conditions are perceived.

Table 1.

Perceptual judgment errors in Experiment 1A, 1B, and 1C relative to the 100 pixel comparator target.

	Perceptual Judgment Errors in Experiment 1		
	Experiment 1A	Experiment 1B	Experiment 1C
	101.29 pixels	97.1 pixels	104.62 pixels
Comparator Target			
100 pixels	=	≠	≠

Figure Captions: Experiment 1A, 1B, and 1C

Figure 1. Mean ending size (pixels) and standard error as a function of condition across Experiment 1A, 1B, and 1C against 100 pixel comparator target.

Figure 2. Mean ending size (pixels) and standard error as a function of starting size across Experiment 1A, 1B, and 1C against the 100 pixel comparator target.

Figure 1

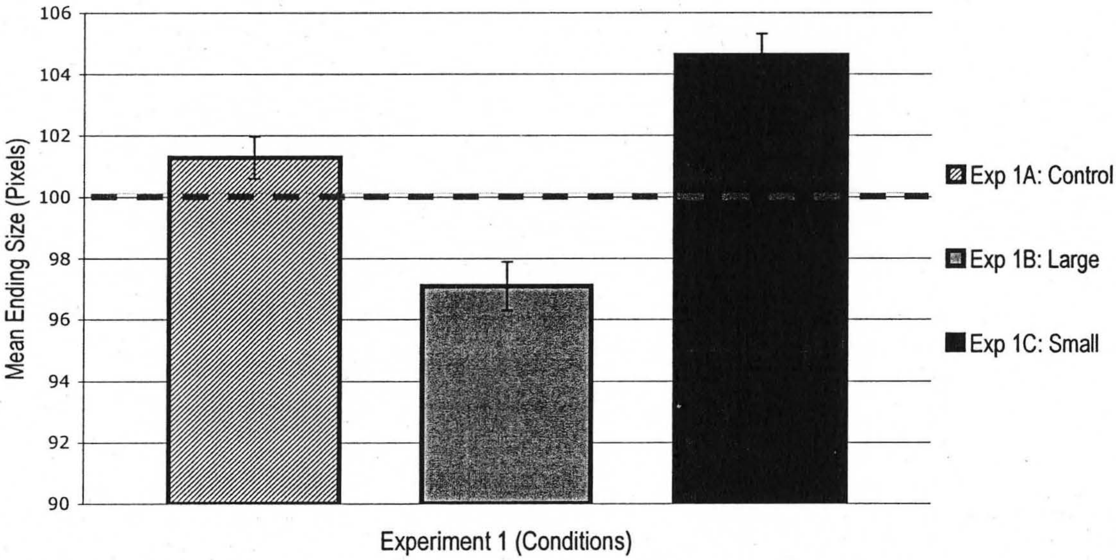
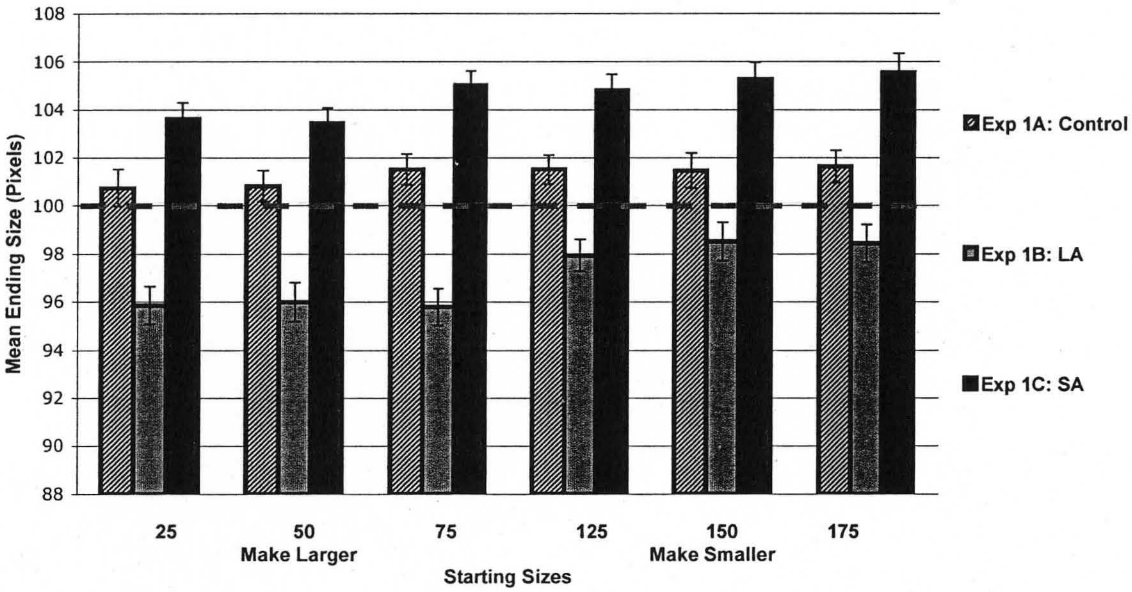

106
104
102
100
98
96
94
92
90
Mean Ending Size (Pixels)
Exp 1A: Control
Exp 1B: Large
Exp 1C: Small
Experiment 1 (Conditions)

Figure 2



108
106
104
102
100
98
96
94
92
90
88
Mean Ending Size (Pixels)
Exp 1A: Control
Exp 1B: LA
Exp 1C: SA
25
50
75
125
150
175
Make Larger
Make Smaller
Starting Sizes

EXPERIMENT TWO

2.0 Introduction

The three studies comprising Experiment 1 investigated perceptual error under both Ebbinghaus illusionary Conditions and a non-illusionary condition in repeated predictable environments. In Experiment 2 we address the question as to what happens with regard to these illusory biases when the LA and SA illusionary conditions and the non-illusionary condition are presented in the same stimulus array (combined) in a repeated and random exposure?

There is reason to believe that illusionary effects will differ when presented in combination than when presented in isolation. As previously noted, Helson (1947) proposed the Adaptation Level Theory (ALT) which states that with every excitation-response configuration an assumed stimulus (which represents the pooled effects of all the previous stimuli) will be constructed. It is this point of pooling that the organism can then be titled attuned or adapted. Thus, Helson (1947) suggested that for every stimulation moment there is an adaptation level that can change with time and with varying stimuli conditions. It is assumed then, that this internal representation will regress towards the mean if all influential stimuli have equally competing influences. Therefore, with respect to the Ebbinghaus Illusion, it is anticipated that the LA and SA conditions will regress towards the mean of 100 pixel comparator more so then they did when presented in isolated in Experiment 1. In other words, when all Ebbinghaus conditions are presented in combination and over the period of several trials, the illusory effects of both LA and SA conditions will be lessened with this adaptation being reflected in smaller undershoot and overshoot biases respectively.

However, when investigating the ALT, it is also important to acknowledge that the illusionary stimuli may have unequal illusionary influences (as seen in Experiment 1; LA and SA demonstrated differential perceptual errors). Therefore, investigating the adaptation level effects in a combined illusory stimulus environment may potentially mediate the illusory effects of other individual illusory condition in the environment with a regression, not towards the mean, but rather in the direction of the more salient stimulus (i.e., in this case the LA illusion). A potential explanation for this potential shifting pattern of results could be suggested by a hysteresis effect wherein the value of given property depends to a great deal upon the past history of the system. Past research investigating the Ebbinghaus Illusion has made implicit assumptions with respect to the stimulus arrays such that they are essentially immune to these hysteresis effects. Investigation into the potential existence of hysteresis as a mechanism behind the ALT, investigates then the dependence upon combined illusory stimulus environments, where any one or combination of illusionary stimuli mediate the illusory effects of an individual illusory condition. Hysteresis is definitely one area of concern that must be taken into consideration when investigating the Ebbinghaus Illusion in both isolated and combined environments.

The purpose of this study then, was to examine perceptual error under both Ebbinghaus illusionary Conditions and a non-illusionary condition when combined in a repeated and random stimulus array thereby exploring the possibility of adaptation when both illusory and non-illusionary conditions are combined within a random and unpredictable environment. It is anticipated that an adaptation level will result. However, the effects of any particular illusion will not regress towards the target mean (100 pixels), but rather demonstrate a hysteretic change wherein, based on results revealed in Experiment 1, (LA: -2.9% undershoot bias and SA: +4.62 % overshoot bias), the pattern of adaptation will shift up in the direction of the SA.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 20 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as employed in Experiment 1A.

Procedure

The task was an exact replica of Experiment 1A, except that participants manipulated the physical size of an isolated circle (target disc) on the right side of the computer monitor to perceptually match the physical size of a target circle (comparator target) on the left side of the computer monitor that appeared in one of three forms; 1) an Isolated Condition (Experiment 1A), 2) a Large Annuli Condition (Experiment 1B), or 3) a Small Annuli Condition (Experiment 1C). Similar to experiment 1, participants manipulated the right side target circle by moving either horizontal or vertical sliders, which were controlled using a computer mouse. All other methodological aspects of Experiment 1 were maintained.

For all trials, regardless of size, the distance between the center of the left target and the center of the right target was 16 cm, thus the center of each target was positioned at 8 cm on each side of the midline. As previously mentioned, the left side target circles appeared in one of three forms; 1) an Isolated Condition, 2) a LA Condition in which the left target was surrounded with 5 large circular annuli (5.5 cm in diameter), or 3) a SA Condition in which the left target was surrounded with 11 small circular annuli (1.0 cm in diameter). The left central target remained 100 pixels in size (3 cm in diameter) throughout the experiment (see Figure 1). Manipulations of the isolated right side target were achieved by either increasing or decreasing the diameter of the isolated right side target from one of four designated starting sizes. Two designated “increasing” starting sizes were 50 %

and 75 % of the size of the left central target (1.5 cm and 2.25 cm in diameter). The two designated "decreasing" starting sizes were 125 % and 150 % of the size of the left central target (3.75 cm and 4.5 cm in diameter). The distances between the edges of the surrounding annuli and the edge of central target were 1.3 cm in both LA and SA conditions. The gaps between each annulus were 1.0 cm in both the LA and SA conditions.

Experimental Design and Data Analysis

A 3 (condition) x 4 (starting size) x 2 (direction) x 5 (sensitivity) analysis of variance (ANOVA) was conducted on the perceptually judged physical manipulations. The dependent measure for the perceptually judged physical manipulations was the actual physical ending size of the right isolated target circle expressed in pixels. Multiple factor Main effects and all interactions were further explored using Tukey's *HSD* procedure. In addition, and in order to determine the magnitude of the size-match error, the final end size of the manipulated stimulus (in pixels) was compared to a 100 pixels (i.e., the size of the control stimulus). As well a macro was constructed to organize each condition's perceptual estimation in the order it which trial was performed. The trial order was run as a 3 (Current) by 3 (Previous) repeated measures ANOVA, to verify if there was any trial- to-trial carry over effects.

Results

A main effect for Condition, $F(2, 20) = 35.39$; $p.<0.00001$, was evident with post-hoc analysis confirming that the isolated condition misperception of 98.19 pixels (underestimated by 1.81 pixels) was significantly different from both the LA condition of 96.47 pixels (underestimated by 3.54 pixels) as well as the SA condition of 101.59 pixels (overestimated by 1.59 pixels). The post-hoc analysis confirmed that LA condition was significantly different from the SA condition.

The ANOVA also revealed a main effect for Starting Size, $F(3, 30) = 6.67$; $p.<0.01$. The post-hoc analysis confirmed that significant differences arose between the 50% and 75% increasing starting sizes and the 150% decreasing starting size. On average, the two increasing starting sizes were not significantly different from each other, and the two decreasing starting sizes were also not significantly different from each other. On average, the mean of the increasing starting sizes were significantly different from the mean of the two decreasing starting sizes (Average error on “increase” trials = 1.73 pixels; average error on “decrease” trials = 0.77 pixels).

A main effect for Direction of the slider, $F(1, 10) = 14.67$; $p.<0.01$, was evident with post-hoc analysis confirming that the horizontal slider (98.44 pixels) was found to be significantly less accurate then the vertical slider (99.05 pixels).

Data Analysis Collapsed Over Sensitivity

Since sensitivity was not present as a main effect in Experiment 1 and remained non-significant in Experiment 2, a 3 (condition) x 4 (starting size) x 2 (direction) analysis of variance (ANOVA) was additionally conducted on the perceptually judged physical manipulations. The dependent measure for the perceptually judged physical manipulations was the actual physical ending size of the right isolated target circle expressed in pixels. As well a macro was constructed to organize each condition's perceptual estimation in the order in which it was performed. The trial order was run as a 3 (Current) by 3 (Previous) repeated measures ANOVA to verify if there was any trial-to-trial carry over effects. It is anticipated that if trial-to-trial carry over effects are present, then an inverted "V" type pattern with previous control, LA, and SA conditions across the x-axis would be evident. Specifically, the LA condition would the have the lowest quantification results, with the control in the middle and the SA condition having the highest quantification results, as predicted by the illusion. Additionally, and to compare illusory biases across each condition relative to whether it was presented in isolation or combination, three between-protocol mixed designed analyses of variance (ANOVA) were conducted comparing each condition in Experiment 2 with its comparable isolated condition in Experiment1.

Results (collapsed over Sensitivity)

A main effect for Condition, $F(2, 20) = 33.18$; $p.<0.00001$, was evident with post-hoc analysis confirming that significant differences exist between the isolated condition of 98.19 pixels (underestimated by 1.81 pixels) and both the LA condition of 96.37 pixels (underestimated by 3.63 pixels) as well as the SA condition of 101.59 pixels (overestimated by 1.59 pixels). Post- hoc analysis also confirmed that the LA condition was significantly different from the SA condition (see Figure 2).

A main effect for Starting Size, $F(3, 30) = 7.84$; $p.<0.001$, was evident with post-hoc analysis confirming that significant differences existed between the 50% and 75% increasing starting sizes and the 150% decreasing starting size (see Figure 3) with the two increasing and decreasing starting sizes were not significantly different from each other. On average, the mean of the two increasing starting sizes were significantly different from the mean two decreasing starting sizes (Average error on "increase" trials = -1.80 pixels; average error on "decrease" trials = -0.77). Overall, the main tendency was to underestimate by 1.29 pixels.

A main effect for Direction of the slider, $F(1, 10) = 12.84$; $p.<0.01$, was evident with post-hoc analysis confirming that perceptual underestimations under the horizontal slider (98.44 pixels) was significantly less accurate then perceptual underestimations in the vertical slider (98.98 pixels) (see Figure 4).

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 98.19 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation in this experiment was significantly different from 100. The mean target ending target size when under the LA condition of 96.37 pixels was significantly different from 100 as well. However, the SA condition of 101.59 pixels was not significantly different from 100 (see Table 1).

When the perceptual error found in the horizontal slider of 98.44 pixels was compared against the value of 100 pixels, it was confirmed that the underestimation was not significantly different from 100. However, when the overall perceptual error in the vertical slider of 98.98 pixels was compared against the value of 100 pixels, it was confirmed that the underestimation was not significantly different from 100 (see Table 2).

Trial Order Analysis

A main effect was revealed for the Current Condition $F(2, 20) = 38.30$; $p. < 0.00001$. Post-hoc analysis revealed that the control condition (98.11 pixels) was significantly different from the LA condition (96.47 pixels), as well as the SA condition (101.57 pixels). Also post-hoc analysis revealed that the SA condition was significantly different from the LA condition. There was no main effect for Previous Condition nor was there a Current by Previous Conditions interaction.

Between- Experiment Analysis

A 4 (starting size) x 2 (direction) between- experiment analysis of variance (ANOVA) was conducted comparing each isolated condition in Experiment 1(A, B, and C) with their comparable mixed condition in Experiment 2. The dependent measure for the perceptually judged physical manipulations was the actual physical ending size of the right isolated target circle expressed in pixels. Multiple factor Main effects and all interactions were further explored using Tukey's *HSD* procedure. In addition, and in order to determine the magnitude of the size-match error, the final end size of the manipulated stimulus (in pixels) was compared to a 100 pixels (i.e., the size of the control stimulus).

Experiment 1A versus Experiment 2

The reason for conducting a between-experiment analysis between Experiment 1A and Experiment 2 was to investigate if adaptation perceptually influenced the control condition in experiment 2. If adaptation does not exist then the control condition in Experiment 1A will not be significantly different from the control condition combined within Experiment 2. However, if the anticipated adaptation does occur, as stated and predicted by the ALT, then the control condition in Experiment 1A will be significantly different from the control condition combined within Experiment 2, suggesting that the LA and SA conditions were influential on the overall perceived accuracy of the control condition in Experiment 2.

Results

A main effect for the Between-Experiment Factor $F(1, 20) = 8.93$; $p.<0.01$, was evident with post-hoc analysis confirming that the control condition in Experiment 1A (101.34 pixels) was significantly different from the control condition combined within Experiment 2 (98.19 pixels) (see Figure 5).

Post Hoc Analysis to Comparable Condition in Experiment 1A

When the overall misperception of the control condition in Experiment 2 (98.19 pixels) was compared against the comparable condition in Experiment 1

(101.34 pixels), it was confirmed that the underestimation in Experiment 2 was significantly different from the overestimation from Experiment 1A (see Table 1).

Discussion

The perceptual error of the control condition in Experiment 2 was significantly different from the perceptual error of the isolated control condition (Exp. 1A) This result demonstrates the presence of a degree of adaptation where the perception of the control condition was significantly influenced by the presence of the LA and SA illusionary conditions within the stimulus set. The results also demonstrate a hysteretic change of the control condition, where the perceptual biases associated with the control condition changed from a slight but non-significant overshoot in Experiment 1A, to a significant undershoot when combined in Experiment 2.

The results suggest that there is significant difference in the ability to accurately size match a target in a predictable non-illusionary environment compared to when the target is combined with illusion inducing stimuli. Overall, the perceptual error changes from a state of accurate estimation in Experiment 1A to a significant undershoot when combined Experiment 2 with illusionary conditions.

Experiment 1B versus Experiment 2

The purpose behind conducting a between-experiment analysis between Experiment 1B and Experiment 2 was to investigate if adaptation perceptually influenced the LA condition when combined in Experiment 2. If adaptation does not exist then the LA condition in Experiment 1B will not be significantly different from the LA condition combined within Experiment 2 suggesting that the combined stimulus array with the SA and control conditions did not have any influence on the LA overall misperceptions. However, if the anticipated adaptation is present as suggested by the ALT, then the LA condition in Experiment 1B will be significantly different from the LA condition combined within Experiment 2, suggesting that the SA and control conditions were influential to the overall misperception that resulted.

Results

A main effect for Starting Size, $F(3, 60) = 15.48$; $p.<0.00001$, was evident with post-hoc analysis confirming that significant differences existed between the decreasing starting size of 125% and 150% compared to each of the increasing starting sizes of 50% and 75%. Post-hoc analysis confirmed that no significant difference existed between either the two increasing starting sizes, or the two decreasing starting sizes. On average, the mean of the two increasing starting sizes were significantly different from the mean two decreasing starting sizes (Average error on "increase" trials = -4.26 pixels; average error on "decrease" trials = -2.33).

Post Hoc Analysis to Comparable Condition in Experiment 1B

When the overall perceptual error of the LA condition in Experiment 2 (96.37 pixels) was compared against the comparable condition in Experiment 1B (97.1 pixels), it was confirmed that the underestimation in Experiment 2 was not significantly different from the underestimation from Experiment 1B (see Table 1).

Discussion

The perceptual error of the LA condition in Experiment 2 was not significantly different from the perceptual error of the isolated LA condition (Experiment 1B). These results suggest that LA condition was not perceptually influenced by the present of the SA and control conditions, and therefore, no adaptation effects were seen between the two LA conditions. Overall then, there is no difference perceptually in the ability to size match a target under the LA influence, in a predictable environment compared to when it is in an unpredictable random environment.

Experiment 1C versus Experiment 2

The purpose behind conducting a between-experiment analysis between Experiment 1C and Experiment 2 was to investigate if adaptation occurred in SA condition combined in Experiment 2. If adaptation does not exist then the SA condition in Experiment 1C will not be significantly different from the SA condition combined within experiment 2. However, in accordance with the ALT, adaptation should be present and therefore, the SA condition in Experiment 1C will be significantly different from the SA condition combined within Experiment 2 thus suggesting that the combined stimulus array with the LA and control conditions were influential to the overall misperception that resulted.

Results

A main effect for the Between-Experiment Factor $F(1, 20) = 7.05$; $p.<0.05$, was evident with post-hoc analysis confirming that the SA condition in experiment 1C (104.63 pixels) was significantly different from the SA condition combined within experiment 2 (101.59 pixels) (see Figure 6).

A main effect for Starting Size, $F(3, 60) = 6.44$; $p.<0.001$, was also present with post-hoc analysis confirming that the only significant difference arose between the largest starting size of 150% (103.79 pixels) and the smallest starting size of 25% (102.34 pixels). Additionally, post-hoc analysis revealed that no significant differences were evident between either the two increasing starting sizes, or the two decreasing starting sizes. However, the average misperception of the two increasing starting sizes of 102.63 pixels (overestimated by 2.63 pixels) was significantly different from the average misperception of the two decreasing starting sizes of 103.59 pixels(overestimated by 3.59 pixels).

Analysis also revealed two significant interactions. A Group by Starting Size interaction effect $F(3, 60) = 2.77$; $p.<0.05$, was evident with post-hoc analysis confirming that the increasing starting sizes were not significantly different from the decreasing starting sizes found in Experiment 1C. However, in Experiment Two, the increasing starting sizes were significantly different from the decreasing starting sizes. Also, post-hoc analysis further confirmed that significant differences arose between each group across each of the four starting sizes.

A Group by Direction interaction effect $F(1, 20) = 6.05$; $p.<0.05$, was evident with the post-hoc analysis confirming that there was no significant differences within group (Experiment 1C and Experiment 2) across slider direction (horizontal and vertical).The significant differences arose when comparing slider directions between groups.

Post Hoc Analysis to Comparable Condition in Experiment 1C

When the overall misperception of the SA condition in Experiment 2 (101.59 pixels) was compared against the comparable condition in Experiment 1C (104.62 pixels), it was confirmed that the overestimation in Experiment 2 was significantly less than that observed Experiment 1C (see Table 1).

Discussion

Adaptation effects were present as demonstrated by the significant perceptual error difference between the SA condition in Experiment 2, and the SA condition in Experiment 1C. Specifically, the SA condition in Experiment 2 exhibited a smaller overshoot bias compared to the SA in Experiment 1C, suggesting once again a hysteretic shift dominated by the LA condition.

Overall, results suggest that there is a difference perceptually in the ability to size match a target under the SA illusionary influence, in a predictable environment compared to when it is in an unpredictable random environment.

Discussion (Experiment 2).

All conditions were significantly different from each other. The LA resulted in a slight but non-significant undershoot error, whereas the SA condition resulted in significantly less overshoot error compared to experiment 1C, becoming not significantly different from the100 pixel target value. The control condition also regressed from a small and non-significant overshoot to a significant undershoot when combined with LA and SA conditions. The Between-Experiment analysis confirms that in Experiment 2 there was a significantly greater undershoot in both the control and SA condition with a slight but non-significant undershoot increase in LA condition when compared to their isolated comparable condition in Experiment 1. These perceptual changes of the control and SA condition in the combined illusionary environments demonstrate their susceptibility to illusionary influences that the LA condition may infer in that the control and SA conditions appear take on the characteristics of the LA condition (see Figure 7). The overall perceptual error patterns for each condition in Experiment 2 suggests that adaptation effects did occur in this combined stimulus environment, but was not present in the traditional sense as proposed by the ALT, but rather demonstrated a hysteretic change biased by the LA condition.

Anticipated by the adaptation level theory, all illusionary misperceptions would regress towards the mean if a true and equal perceptual stimuli adaptation level was present. However, as hypothesized it was suggested that a hysteretic changed would be present and effect the adaptation by demonstrating an overall shift in the perceptual error pattern of each condition. However, it was hypothesized that this hysteretic change would be biased by the SA condition, based on its strong perceptual bias in Experiment 1C. However, opposite to the hypothesized results, adaptation effects revealed in Experiment 2 were biased by the LA condition, where control and SA condition patterns decreased and the LA condition perceptual bias increased, overall revealing a downward shift.

Overall, participants underestimated across all starting sizes. The starting size pattern was very similar to the starting size pattern found in Experiment 1B, due to the LA condition's perceptual dominating effect. The starting size patterns also demonstrate anticipated effects as proposed by the range effect.

Durgin and Hammer (2001) suggested that overall adaptation effects were biased sequentially when compared to the a similar simultaneous comparison. They suggested that potential short-term aftereffects arose and affected the perception of the next stimulus in the set. They term these as "dynamic aftereffects" and in their study (2001) and demonstrated that they seemed to be influenced by prior repeated exposure. Based on the similar adaptation effects revealed in Experiment 2, it is important to investigate the effects of trial order. The results of trial order effect analysis in Experiment 2 suggest that the adaptation effects are not simply due to trial-to-trial carry over effects, but rather accumulated effects of repeated exposure thus suggesting that it is not short-term aftereffects, but rather long term adaptation level effects.

Conclusion (Experiment 2)

All three conditions were found to be significantly different from each other and the pattern of misperceptions for the LA and SA condition were as anticipated (perceptual estimations of the LA condition undershot and the SA condition overshot the comparator target). However, the perceptual error bias of the control condition changed dramatically when placed within the combined illusionary environment. The evidence suggests that there are different perceptual illusionary effects for stimuli when presented in an isolated environment (as in Experiment 1) than when presented as a part of a combined stimulus array (as in Experiment 2). Therefore, the results of Experiment 2 suggest that adaptation does occur, but that this adaptation adopts a form wherein participants seem to treat every condition like LA condition.

Overall Conclusion (Experiment 1A, 1B, and 1C and Experiment 2)

Experiment 1 was not only able to quantify perceptual biases as they relate to matching match target sizes in both illusory and non-illusionary environments. Specifically, the expected Illusionary biases were present and comparable with previous research. In Experiment 1, the SA condition demonstrated the strongest illusionary effect. Therefore it was anticipated that the SA condition would be the mediating illusionary condition in Experiment 2. However, results of Experiment 2, show that the nature of both the SA illusionary bias and the control condition bias were significantly mediated by the LA condition. This overall shift in perceptual error is partially consistent with ALT however, the results suggest that the LA condition is the more salient stimulus and that the two illusionary conditions used in this Experiment are perceptually unequal in their illusionary influences.

Therefore, different illusionary stimulus events that are combined in a random multiple exposure protocol, leads to an adaptation characterized by a hysteretic shift that is biased by the most salient illusionary condition. It has to be acknowledged as well that perceptual errors in isolation really do not suggest the strength of their illusionary influence when combined in a random environment.

Table 1.

Perceptual judgment errors in Experiment 2 relative to the 100 pixel comparator target and isolated conditions from Experiment 1.

	Perceptual Judgment Errors in Experiment 2		
	Control Condition 98.19 pixels	Large Annuli Condition 96.37 pixels	Small Annuli Condition 101.59 pixels
Comparator Target 100 pixels	≠	≠	=
Experiment 1A 101.29 pixels	≠		
Experiment 1B 97.1 pixels		=	
Experiment 1C 104.62 pixels			≠

Table 2.

Perceptual judgment errors in Experiment 2 relative to the 100 pixel comparator and Experiment 1B.

	Perceptual Judgment Errors in Slider Direction for Experiment 2	
	Horizontal Slider (98.44 pixels)	Vertical Slider (98.98 pixels)
Comparator Target 100 pixels	=	=
Experiment 1B Overall Perceptual Error (98.72 pixels)	=	=

Figure Captions: Experiment 2

Figure 1. Illustration of the experimental test conditions employed in Experiment 2 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixels comparator target and the mean undershoot bias of 1.29 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the100 pixels comparator target and the mean undershoot bias of 1.29 pixels.

Figure 4. Mean ending size (pixels) and standard error as a function of slider direction against the 100 pixel comparator target and the mean undershoot bias of 1.29 pixels.

Figure 5. Mean ending size (pixels) and standard error as a function of condition (control) and experiment (Experiment 1A and Experiment 2) against the 100 pixel comparator target.

Figure 6. Mean ending size (pixels) and standard error as a function of condition (SA) and experiment (Experiment 1C and Experiment 2) against the 100 pixel comparator target.

Figure 7. Mean ending size (pixels) and standard error as a function of experiment (Experiment 1 and Experiment 2) and condition (control, LA, and SA).

Figure 1

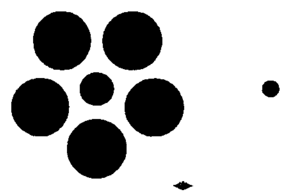
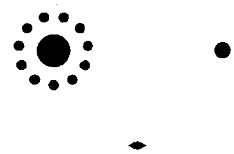
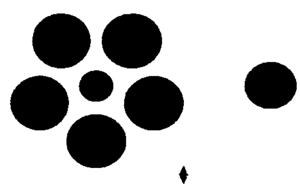
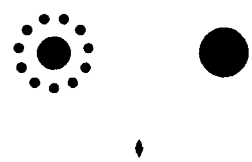
	Conditions In Experiment Two		
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target		
Trials	***Left Central Target - Isolated***	***Left Central Target - Large Annuli***	***Left Central Target - Small Annuli***
Increase *Right Target Starting Size =1.50 cm*	*Horizontal Slider* *Right to Increase / Left to Decrease*		
			
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider* *Down to Increase/ Up to Decrease*		
			

Figure 2

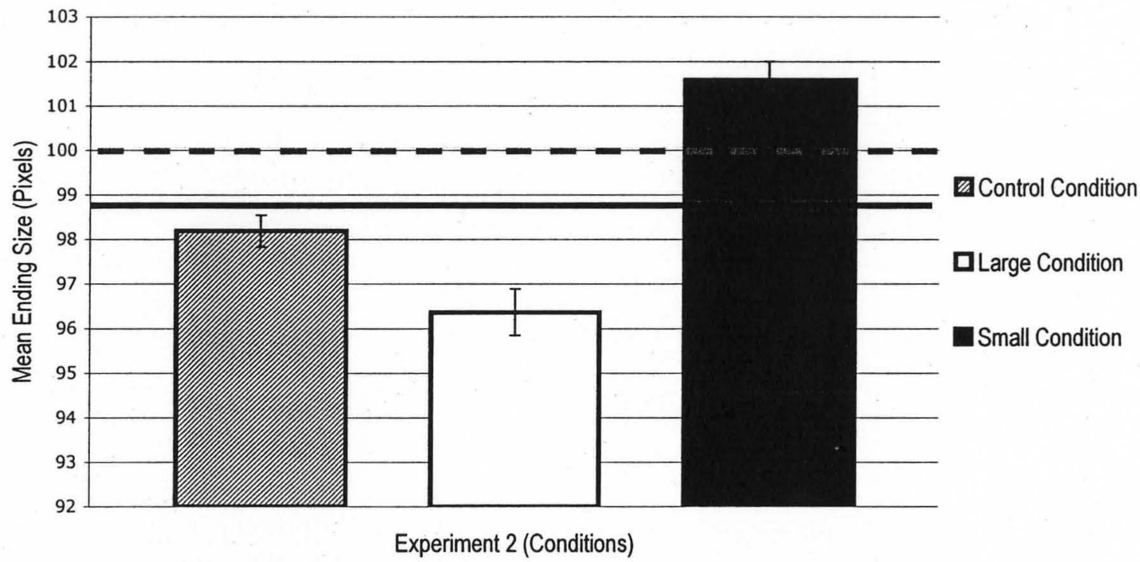

103
102
101
100
99
98
97
96
95
94
93
92
Mean Ending Size (Pixels)
Experiment 2 (Conditions)
Control Condition
Large Condition
Small Condition

Figure 3

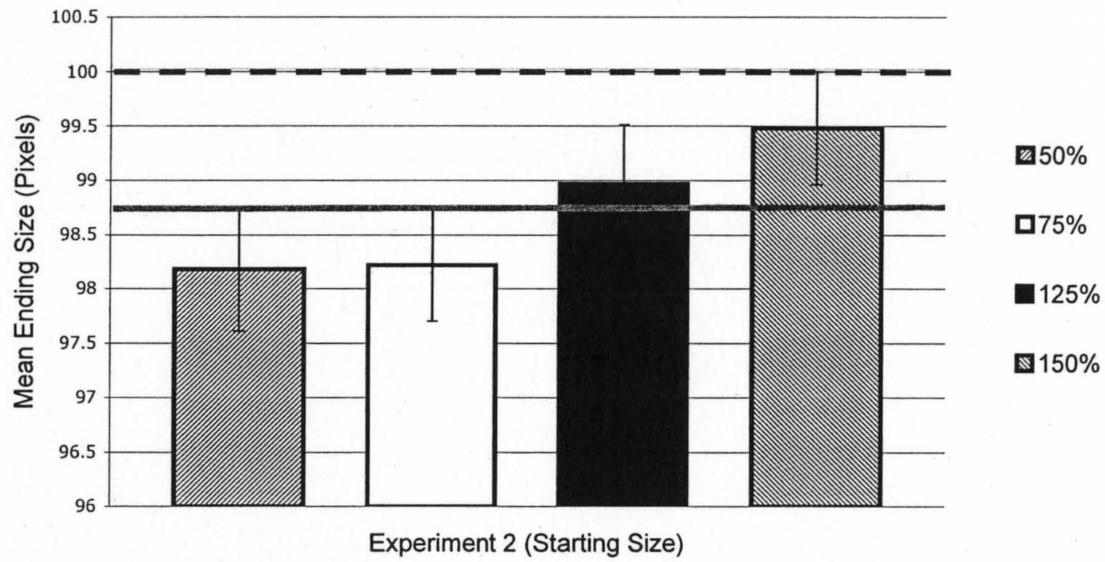

100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
Mean Ending Size (Pixels)
Experiment 2 (Starting Size)
50%
75%
125%
150%

Figure 4

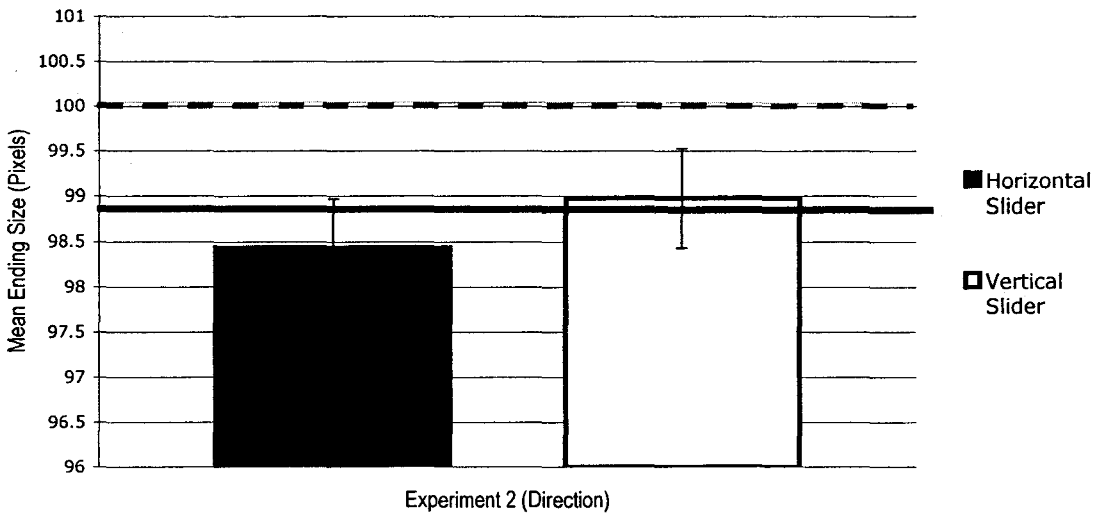

101
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
Mean Ending Size (Pixels)
Experiment 2 (Direction)
Horizontal Slider
Vertical Slider

Figure 5

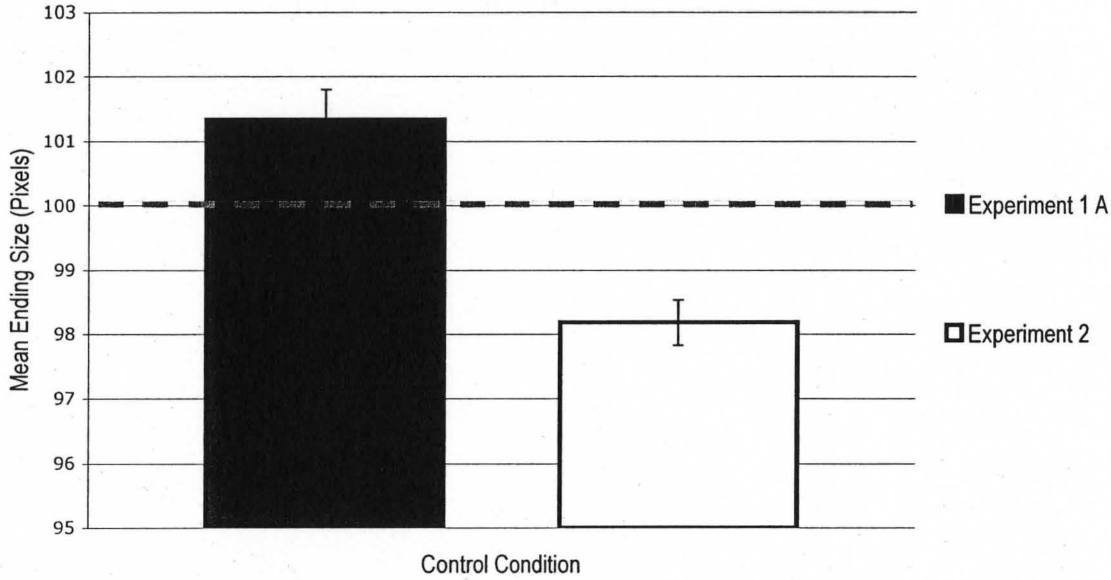

103
102
101
100
99
98
97
96
95
Mean Ending Size (Pixels)
Experiment 1 A
Experiment 2
Control Condition

Figure 6

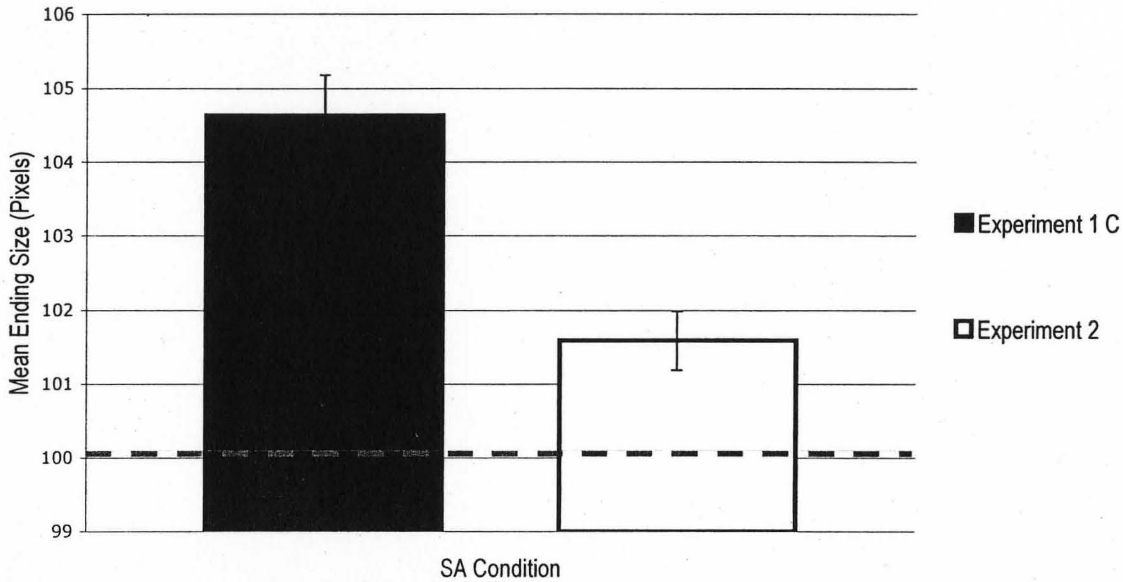
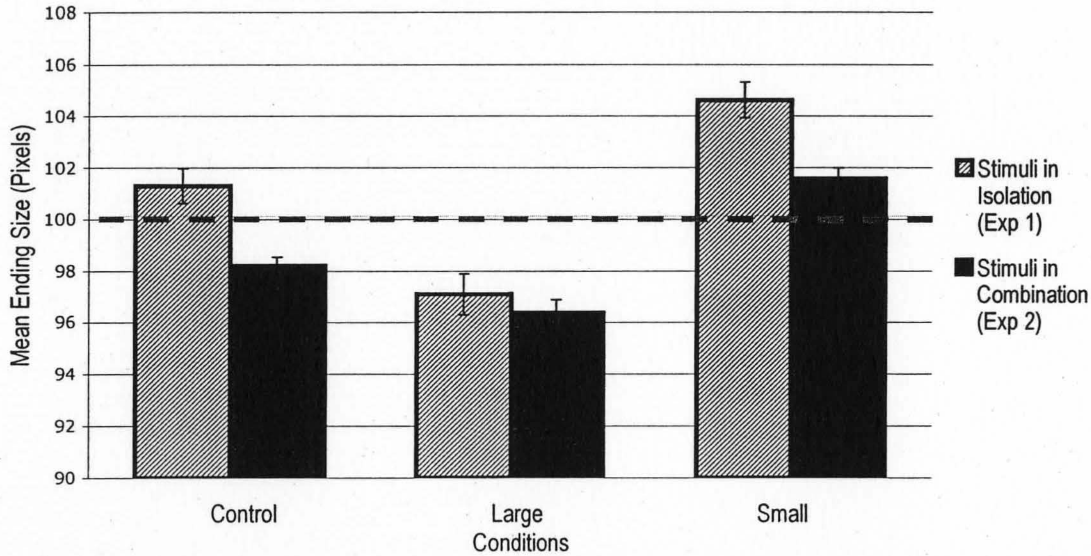

106
105
104
103
102
101
100
99
Mean Ending Size (Pixels)
SA Condition
Experiment 1 C
Experiment 2

Figure 7



Mean Ending Size (Pixels)
108
106
104
102
100
98
96
94
92
90
Control
Large
Conditions
Small
Stimuli in Isolation (Exp 1)
Stimuli in Combination (Exp 2)

EXPERIMENT THREE

3.0 Introduction

Experiments 1 and 2 were designed to quantify the perceptual effects that arise from the Ebbinghaus Illusion in both isolated predictable environments and randomly combined unpredictable environments. Although motor interactions were minimized in Experiments 1 and 2, participants still had to interact with the apparatus by physically manipulating the horizontal and vertical sliders. In Experiment 3, we seek to further minimize motor involvement by eliminating participant interaction with the slider.

In Experiment 2 a main effect for Slider Direction was present, wherein it seemed that the horizontal slider (98.44 pixels) was less accurate then the vertical slider (98.98 pixels), when compared to the 100 pixel target. These results then suggest that a motor component influence may have possibly effected the results and adaptation aspects found in Experiment 2.

Research conducted by McBride, Risser, and Slotnick (1987) and Brosvic and Cohen (1988) examined the horizontal-vertical illusion and found that participants made significantly shorter manipulations to the vertical lines, then compared to horizontal lines comparisons. Therefore, the results show that under vertical comparison adjustments in the vertical dimension, an inaccuracy bias exists.

Another possible interpretation of the slider direction effect could be that movements associated with the slider, potentially influenced gaze direction. It has been shown that, when presented with visual stimuli, gaze-dependent neuronal responses have been found within the parietal areas in monkeys (Andersen, Bracewell, Barash, Gnadt, & Fogassi, 1990; Andersen, Essick, & Siegel, 1985; Andersen & Mountcastle, 1983). Nishida, Motoyoshi, Andersen, and Shimojo (2003) claim that the issue of spatial constancy is a central concern in cognitive neuroscience research and demonstrated that gaze direction significantly affected the size aftereffect.. They conclude that investigating visual aftereffects based upon gaze dependent response could be a very useful psychophysical tool. The stimuli in Experiment 2 were presented in the same spatial locations where it is possible that gaze directions were further influenced by the horizontal slider more so then the vertical slider. Thus, it is possible that the horizontal slider movements could reinforce gaze directions, thereby strengthening the illusionary effect, producing a stronger magnitude of perceptual error. The question then remains as to how influential slider direction is to the misperceptions found in Experiment 2?

Therefore the purpose of Experiment 3 was to further remove the motor component associated with target size manipulations and then compare those results to Experiment 2. It was anticipated that slider direction will no longer be significant, as it was in Experiment 2. As well, it was anticipated that a between-experiment analysis comparing Experiments 2 and 3 would reveal no between-experiment effects thus suggesting that the physical manipulations of the slider controls is not influential to the observed illusionary perceptual biases found in Experiment 2.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 18.5 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as employed in Experiment 2 with the addition of a split screen laptop placed directly behind the computer monitor projecting the images to the participants. The split screen laptop projected the experimental screen to the experimenter. The only difference between laptop screen and computer monitor was that the sliders were only visible on the laptop screen to the experimenter. Therefore, sliders were not visible to the participants, nor could they see the experimenter making appropriate slider movements. The experimenter used a computer mouse to manipulate the horizontal and vertical sliders, adjusting the target sizes as instructed by the participants (see Figure 1a and Figure 1b).

Procedure

The task was an exact replica of Experiment 2 except that participants verbally informed the experimenter as to how to manipulate the physical size of the target stimuli. The experimenter then controlled the size of the right side target circle using either the horizontal or vertical sliders in the appropriate directions as per instructed by the participants. The horizontal and vertical sliders were only visible to the experimenter; therefore the participants did not see nor perform any overt limb movements All other aspects of this experiment were the same as Experiment 2 (see Figure 2).

Experimental Design and Data Analysis

Identical data analyses were conducted on Experiment 3 as were employed in Experiment 2 collapsed over sensitivity. Additionally, a 3 (condition) by 4 (starting size) by 2 (direction) between- experiment analysis of variance (ANOVA) was conducted comparing Experiment 3 against experiment 2.

Results

A main effect for Condition, $F(2, 20) = 22.06$; $p.<0.00001$, was present with post-hoc analysis confirming that the control condition of 98.96 pixels (underestimated by 1.04 pixels) was not significantly different from the LA condition of 97.16 pixels (underestimated by 2.84 pixels) but was significantly different the SA condition of 102.06 pixels (overestimated by 2.06 pixles). Post-hoc analysis further confirmed that the LA was significantly different from the SA condition (see Figure 3).

A main effect for Starting Size, $F(3, 30) = 3.55$; $p.<0.05$, was also revealed such that post-hoc results confirmed that the only significant difference occurred between the smallest starting size (50%) and the largest starting size (150%) (see Figure 5). The smallest starting size (98.54 pixels) led to less accurate estimates of ending size than the larger starting size (100.45 pixels). Overall, across all conditions the tendency was to perceptually underestimate by 0.61 pixels (see Figure 4).

Additional post-hoc analysis confirmed that the increasing starting sizes were not significantly different from each other however the two decreasing starting sizes were significantly different from each other. On average, the two increasing starting sizes were not significantly different from the two decreasing starting sizes There was no effect for Direction. (see Figure 5).

Post Hoc Analysis to al Comparator Value (100 pixels)

When the mean target ending size of the control condition of 98.96 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation in this experiment was not significantly different from 100. The mean target ending size when under the LA condition of 97.16 pixels was significantly different from 100. However, the SA condition of 102.06 pixels was not significantly different from 100 (see Table 1).

Trial Order Analysis

A main effect was revealed for the Current Condition $F(2, 20)= 21.89$; $p.<0.00001$. Post-hoc analysis revealed that the control condition (98.94 pixels) was significantly different from the SA condition (101.95 pixels) but not from the LA condition (97.24 pixels). Also post-hoc analysis revealed that the SA condition was significantly different from both the LA and control conditions.

As well, a Current Condition by Previous Condition interaction resulted $F(4,40)= 2.88$, $p.<0.05$. Post hoc analysis revealed that there were no significant differences within each current condition. Rather, the significant differences arose when comparing each current condition across the 3 previous conditions (see Figure 6).

Between-Experiment Analysis (Experiment 3 versus Experiment 2)

The purpose behind conducting a between-experiment analysis of variance (ANOVA) between Experiment 3 and Experiment 2 was to investigate if physical manipulation of slider direction was influential to the overall perceptual errors found in Experiment 2. It was anticipated that no between- experiment effect would be evident, suggesting that the slider direction motor component in this experimental design is not a contributing factor and does not influence the perceptual errors found in Experiment 2.

Results

A main effect for Condition $F(2, 40) = 53.66$; $p.<0.00001$, was evident with post-hoc analysis confirming that all three conditions were significantly different from one another. Also, a main effect for Starting Size $F(3, 60) = 7.92$; $p.<0.001$, was present with post-hoc confirming that the 50%, 75% and 125% starting sizes were significantly different from 150% starting size. As well, a main effect for Direction $F(1, 20) = 9.27$; $p.<0.01$, was revealed and post-hoc analysis confirmed that the vertical slider's perceptual underestimation error was 0.73 pixels, which was significantly different from the horizontal slider's perceptual underestimation of 1.17 pixels. A Condition by Starting Size interaction was revealed, $F(6, 120) = 2.41$; $p.<0.05$, with post-hoc analysis showing that perceptual differences occurred between all test conditions (control, LA and SA conditions) across starting sizes.

Post Hoc Analysis (Experiment 3 versus Experiment 2)

The mean target ending sizes were not significantly different between Experiment 2 and Experiment 3. (Control Condition: Experiment 2 = 98.19 pixels, Experiment 3 = 98.96 pixels; LA condition: Experiment 2 = 96.37 pixels, Experiment 3 = 97.16 pixels; SA condition: Experiment 2 = 101.59 pixels, Experiment 3 = 102.06 pixels) (see Table 1).

Discussion

The control condition was not significantly different from the LA condition as it was in Experiment 2 demonstrating the perceptual strength the LA exerts on the control condition. The fact that the SA condition was significant from the LA condition reveals that it is not as susceptible to the LA condition as the control seems to be. However, the SA condition was not significantly different from the 100 pixel target value, as it was once in experiment 1C. Therefore, the change in perceptual error of both the control and SA conditions, demonstrates that the LA stimulus is a more robust stimulus. The overall adaptation effects again showed a hysteretic shift when compared to isolated conditions in Experiment 1.

A main effect for starting size was present, in which only the extreme starting sizes again were significantly different. Compared to the 100 pixel target value, the smallest starting size was less accurate then the largest starting size. However, when comparing the starting sizes to the overall undershoot of 99.39 pixels the pattern of results for each starting size follows what would be predicted by range effect theory. Here the starting sizes that require the greatest adjustments underestimate the target, whereas the starting sizes that require little adjustments will be overestimated.

Slider direction was not revealed as a main effect in Experiment 3 therefore suggesting that the slider direction effect is not an influential contributor to the overall perceptual errors found in Experiment 3. Post-hoc analysis confirmed that all 3 conditions in Experiment 3 were not significantly different from their comparable conditions in Experiment 2. As well, there was no between- experiment effect between Experiment 3 and Experiment 2, further suggesting that direction of slider effect can be eliminated as a possible contributing influence to overall perceptual errors found in Experiment 2.

The interaction that occurred involving trial order further supports the significant illusionary perceptual errors under each illusionary condition. As anticipated, Significant differences arose when comparing each current condition across the 3 previous conditions. The fact that post-hoc analysis revealed that there were no significant differences within each current condition suggests then that trial order what not influential in the overall misperceptions revealed.

Conclusion

Experimental manipulations performed in Experiment 3 (slider motor component removed) did not influence perceptual errors in Experiment 3 significantly enough to be different from Experiment 2 thereby suggesting that the motor involvement required to manipulate the sliders does not have a significant influence on illusionary misperceptions. As well, hysteretic changes in adaptation effects between all 3 conditions were prevalent in Experiment 3 and were not significantly different from the hysteretic shift revealed in Experiment 2, suggesting once again that the LA condition is a more robust stimulus.

Table 1.

Perceptual judgment errors in Experiment 3 relative to the 100 pixel comparator target and comparable conditions from Experiment 2.

	Perceptual Judgment Errors in Experiment 3		
	Control Condition 98.96 pixels	Large Annuli Condition 97.16 pixels	Small Annuli Condition 102.06 pixels
Comparator Target 100 pixels	=	≠	=
Comparable Experiment 2 Condition	= (Control 98.19 pixels)	= (Large 96.37 pixels)	= (Small 101.59 pixels)

Figure Captions: Experiment 3

Figure 1a. Illustration of the experimental set up (aerial view).

Figure 1b. Illustration of the experimental set up (side view).

Figure 2. Illustration of the experimental test conditions employed in Experiment 3 (one increasing and one decreasing starting size).

Figure 3. Mean ending size (pixels) and standard error as a function of condition against the100 pixel comparator target and the mean undershoot bias of 0.61 pixels.

Figure 4. Mean ending size (pixels) and standard error as a function of starting size against the100 pixels comparator target and the mean undershoot bias of 0.61 pixels.

Figure 5. Mean ending size (pixel) and standard error as a function of slider direction against the 100 pixel comparator target and the mean undershoot bias of 0.61 pixels.

Figure 6. Mean ending size (pixels) and standard error as a function of trial order against the 100 pixel comparator target.

Figure 1a

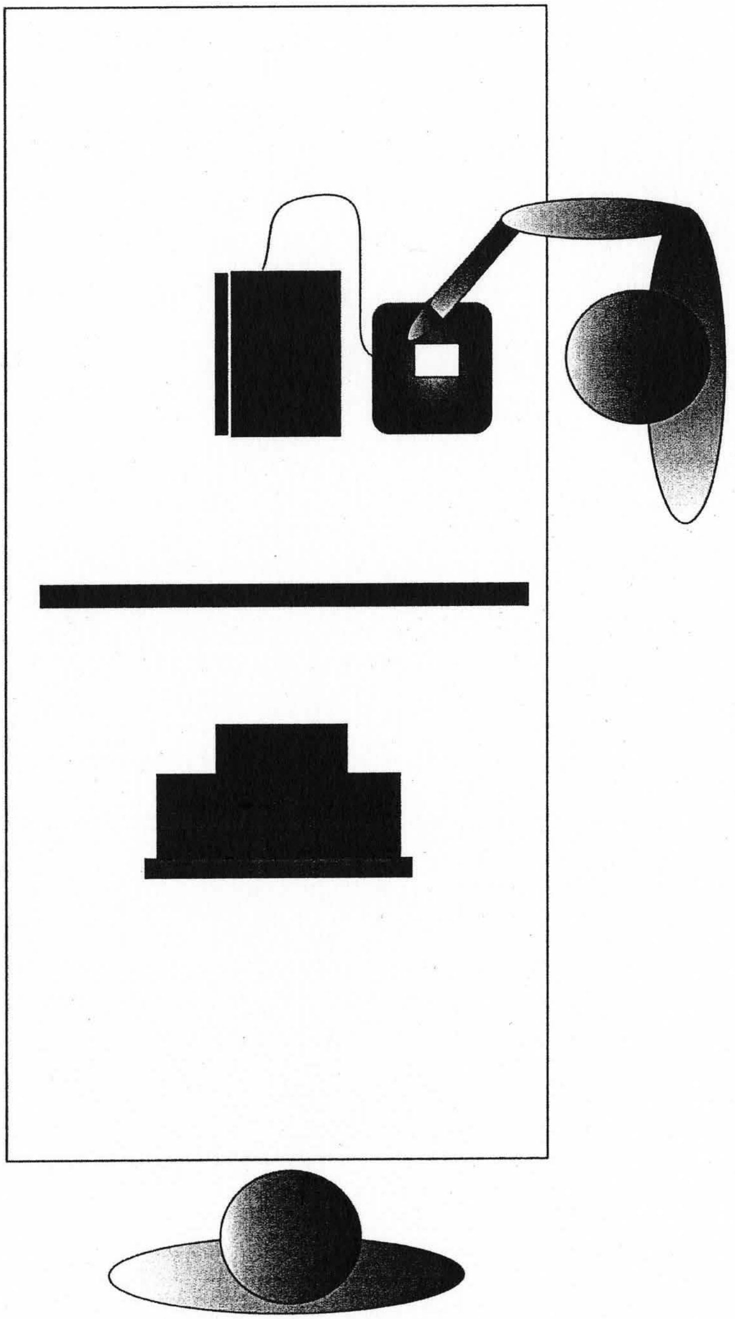


Figure 1b

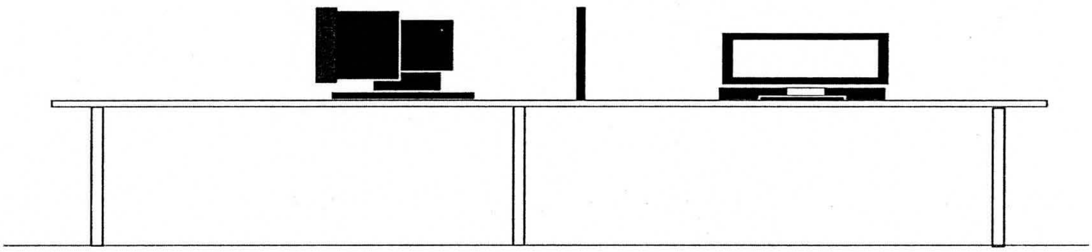


Figure 2

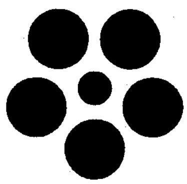
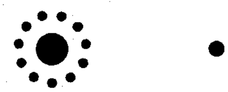
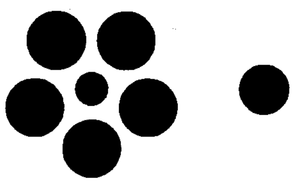
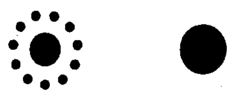
<table>
<tr><td rowspan="2"></td><td colspan="3">Conditions in Experiment Three</td></tr>
<tr><td colspan="3">Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target</td></tr>
<tr><td>Trials</td><td>Left Central Target – Isolated</td><td>Left Central Target - Large Annuli</td><td>Left Central Target - Small Annuli</td></tr>
<tr><td rowspan="2">Increase
Right Target
Starting Size =
1.50 cm</td><td colspan="3">Horizontal Slider
Right to Increase / Left to Decrease</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Decrease Right Target
Starting Size
4.5 cm</td><td colspan="3">Vertical Slider
Down to Increase/ Up to Decrease</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Figure 3

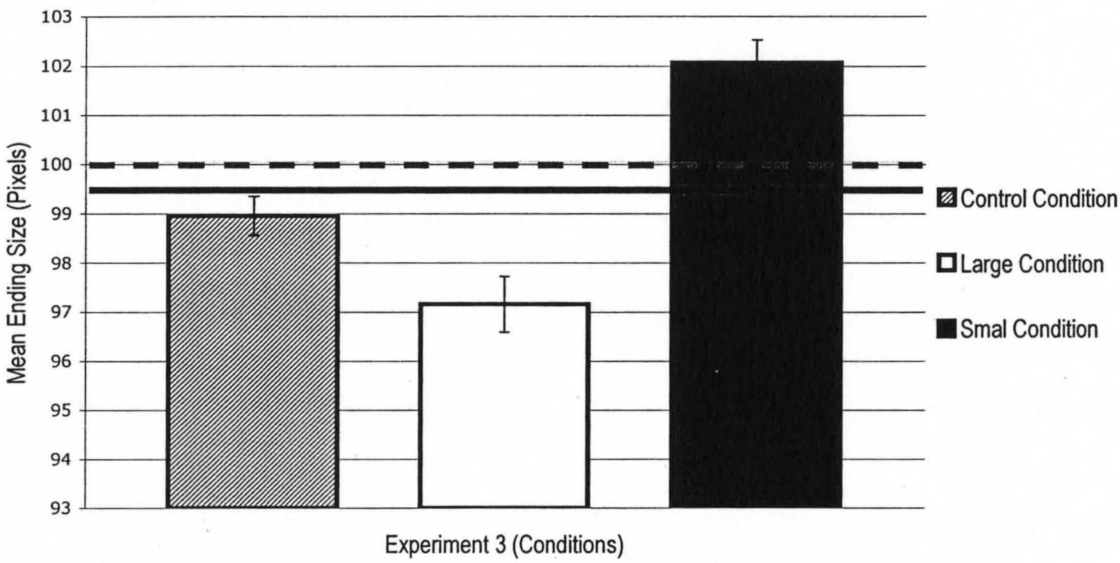

103
102
101
100
99
98
97
96
95
94
93
Mean Ending Size (Pixels)
Control Condition
Large Condition
Smal Condition
Experiment 3 (Conditions)

Figure 4

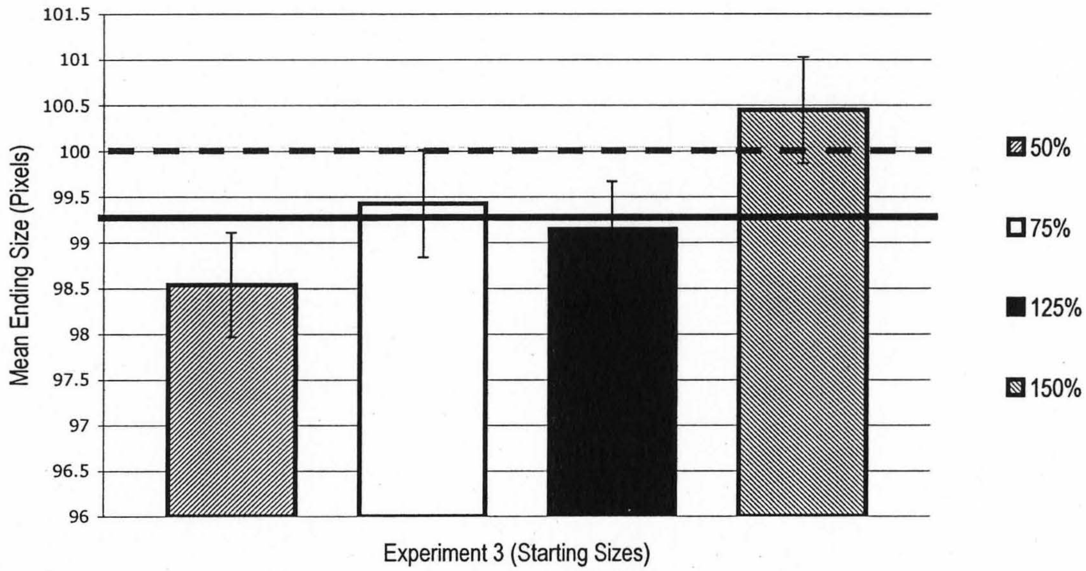

101.5
101
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
Mean Ending Size (Pixels)
Experiment 3 (Starting Sizes)
50%
75%
125%
150%

Figure 5

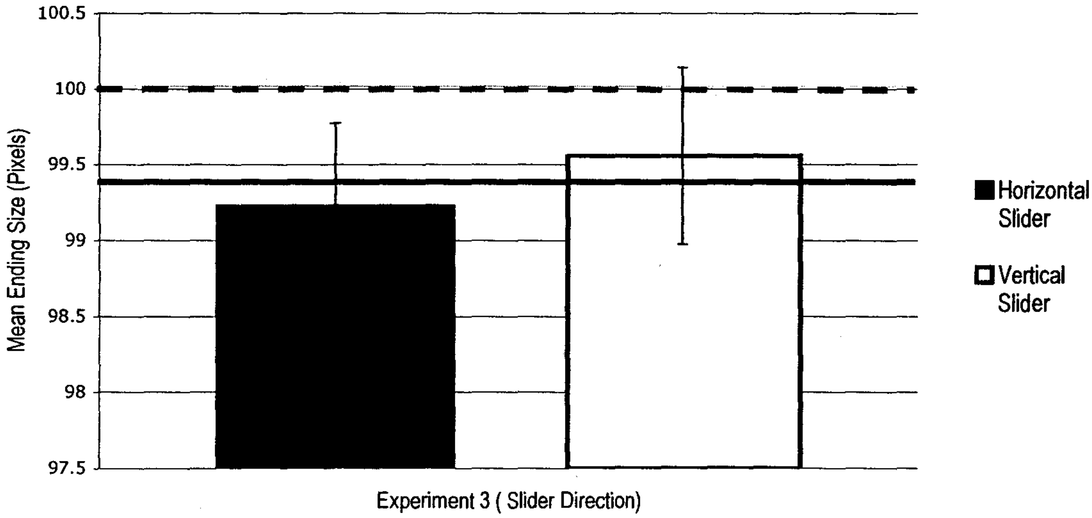
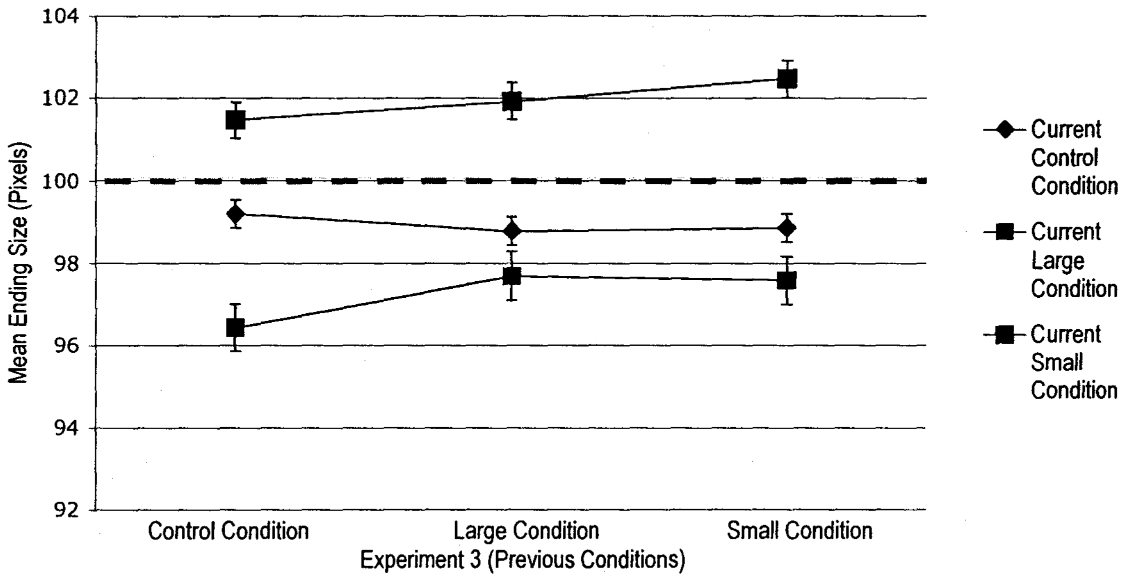

100.5
100
99.5
99
98.5
98
97.5
Mean Ending Size (Pixels)
Experiment 3 (Slider Direction)
Horizontal Slider
Vertical Slider

Figure 6


104
102
100
98
96
94
92
Mean Ending Size (Pixels)
Control Condition
Large Condition
Small Condition
Experiment 3 (Previous Conditions)
Current Control Condition
Current Large Condition
Current Small Condition

EXPERIMENT FOUR

4.0 Introduction

In Experiments 2 and 3, when both the LA and SA Ebbinghaus illusions were included in the stimulus array, the perceptual judgments did not approximate an intermediate stimulus as hypothesized by the adaptation level theory. Rather, the perceptual judgments took on characteristics of the LA condition in which a robust undershoot biased occurred across all conditions. This demonstrated not only the LA condition's salience in eliciting hysteretic shifts in adaptation. The perceptual error undershoot shift that occurred within all 3 conditions in Experiment 2 and Experiment 3, has prompted further questions with respect to the mechanism responsible for these effects. Specifically, do these effects require both illusionary conditions to be present or is one illusionary condition sufficient? As well, does the lack of one condition result in equal misperceptions?

The purpose of Experiment 4 was to investigate whether the SA condition will be strong enough to elicit hysteresis effects when only presented in combination with the control condition thus in Experiment 4, the LA condition was eliminated. Therefore, results will suggest if the observed hysteresis effects require both illusionary extremes upon which adaptive stimulus representations are constructed, or if in this experiment the SA illusionary condition is powerful enough to elicit such an effect on the basis of its single illusory stimulus. It was anticipated that an adaptation effect should result even in an environment with a single illusionary influence.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 21.6 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as employed in Experiment 2.

Procedure

The task was identical to Experiment 2 with the exception that the left side target circles appeared in one of only two forms; 1) an Isolated Condition, or 2) a Small Annuli Condition in which the left target was surrounded with 11 small circular annuli (see Figure 1).

Therefore, the experiment was a 2 (condition) by 4 (starting size) by 2 (direction) design. In total, there were 2 different left target conditions with 4 starting sizes for each condition, tested 10 times randomly for a total of 80 trials.

Experimental Design and Data Analysis

A 2 (condition) x 4 (starting size) x 2 (direction) analysis of variance (ANOVA) was conducted on the perceptually judged physical manipulations. The dependent measure for the perceptually judged physical manipulations was the actual physical ending size of the right isolated target circle expressed in pixels. Multiple factor Main effects and all interactions were further explored using Tukey's *HSD* procedure. In addition, and in order to determine the magnitude of the size-match error, the final end size of the manipulated stimulus (in pixels) was compared to a 100 pixels (i.e., the size of the control stimulus). The trial order was analyzed as a 2 (Current) by 2 (Previous) repeated measures ANOVA, to verify if there was any trial-to-trial carry over effects. Additionally, A 2 (condition) x 4 (starting size) x 2 (direction) analysis of variance (ANOVA) was conducted between experiment 4 and the two comparable conditions in Experiment 2.

Results

A main effect was present for Condition, $F(1, 10) = 13.86$; $p.<0.01$, with post-hoc analysis confirming that the control condition of 99.54 pixels (underestimated by 0.46 pixels) was significantly different from the SA condition of 103.39 pixels (overestimated by 3.39 pixels) (see Figure 2).

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 99.54 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation was not significantly different from 100. The mean target ending size of the SA condition of 103.39 pixels was significantly different from 100 (see Table 1).

Trial Order Analysis

A main effect was revealed for the Current Condition $F(1, 10) = 13.41$; $p.<0.01$, revealing that the control condition (99.53 pixels) was significantly different from the SA condition (103.39 pixels).

Between-Experiment Analysis (Experiment 4 versus Experiment 2)

The purpose behind conducting a between-experiment analysis of variance (ANOVA) between Experiment 4 and Experiment 2 was to investigate if hysteresis effects are mediated by the combination of both illusionary conditions or if the presence of only one of the illusory conditions was sufficient to elicit these effects.. It was anticipated that a between-experiment effect will result, suggesting that the control and SA conditions in Experiment 4 were differentially perceived from those conditions in Experiment 2. Therefore, suggesting that a different hysteretic effect developed when the LA condition was not present.

Results

A main effect for Condition $F(1, 20) = 41.77$; $p.<0.00001$, was evident with post-hoc analysis confirming that the control condition which resulted in an underestimation of 1.14 pixels, was significantly different from the SA condition with its overestimation of 2.49 pixels.

A main effect for Starting Size $F(3, 60) = 4.82$; $p.<0.01$, was also present with post-hoc analysis confirming that the smaller starting sizes were more accurate to the 100 pixel comparator value, then the larger starting sizes. As well, a main effect for Direction $F(1, 20) = 12.05$; $p.<0.01$, was revealed with post-hoc confirming that the horizontal slider (100.39 pixels) was significantly different from the vertical slider (100.96 pixels).

Post Hoc Analysis (Experiment 4 versus Experiments 1 and 2)

When the mean target ending size of the control condition of 99.54 pixels was compared against the comparable condition in Experiment 1A (101.29 pixels) and Experiment 2 (98.185 pixels), it was confirmed that Experiment 4 was not significantly different from either Experiments 1A or 2. When the mean target ending size of the SA condition in Experiment 4 (103.39 pixels) was compared against the comparable condition in Experiment 1C (104.62 pixels) and Experiment 2 (101.59 pixels), it was confirmed that the mean target ending size in Experiment 4 not was significantly different from either overestimation from Experiment 1C or 2 (see Table 1).

Discussion

The main effect for condition was still evident where the SA illusionary condition was perceived to be larger then the control condition. Post-hoc comparisons of the control condition show that there was no significant adaptation effects arising from the presence of the SA condition alone. The control condition perceptual undershoot bias was not significantly different from the 100 pixel comparator target, Experiment 1A, and Experiment 2. Post-hoc analysis also showed that the SA overshoot bias was not significantly different from Experiment 1C and Experiment 2. Therefore, it can be suggested that the SA condition did not have a strong enough illusionary influence to elicit an adaptation effect on the control condition. These results were not as anticipated. Between-experiment comparisons between Experiment 2 and Experiment 4 suggest that there are no significant differences between the control and SA bias when the LA condition is not present.

Conclusion

Misperceptions of the control and SA conditions were the same regardless of whether the LA condition was present or not. Therefore, this experiment demonstrates that the SA stimulus was not strong enough to elicit an adaptation effect as seen in the non-significant perceptual errors of the control condition. As well, there was no hysteretic effect in the perceptual error adaptation patterns. This would have been observed if perceptual error bias of the SA in Experiment 1C increased. Instead the SA regressed towards the 100 pixel value, and demonstrated a non-significant adaptation effect. These results suggest one of, or a combination of, two things: First the possibility that hysteresis effects do require both illusionary conditions to be present in the stimulus set as demonstrated in Experiment 2 and 3. The second suggestion might be that the

SA condition was just not salient enough to elicit the hysteretic effect demonstrating again the idea that all illusionary stimuli are not created equally.

Therefore, the results suggest that the observed hysteresis effects require both illusionary extremes, at least for a weaker illusionary condition upon which adaptive stimulus representations are constructed. The results of Experiment 4 suggest that adaptation levels found in Experiment 2 were highly affected by the LA condition. These results also suggest that the hysteretic shift found in Experiment 2 can either be attributed to the LA condition, which seems to be a more salient illusionary stimulus in combined environments, or that hysteresis needs both illusionary annuli present for effects to occur.

Table 1.

Perceptual judgment errors in Experiment 4 relative to the 100 pixel comparator target isolated conditions from Experiment 1, and comparable conditions in Experiment 2.

	Perceptual Judgment Errors in Experiment 4	
	Control Condition 99.54 pixels	Small Annuli Condition 103.39 pixels
Comparator Target 100 pixels	=	≠
Experiment 1A 101.29 pixels	=	
Experiment 1C 104.62 pixels		=
Comparable Experiment 2 Condition	= (Control 98.19 pixels)	= (Small 101.59 pixels)

Figure Captions: Experiment 4

Figure 1. Illustration of the experimental test conditions employed in Experiment 4 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixel comparator target and the mean overshoot bias of 1.47 pixels.

Figure 1

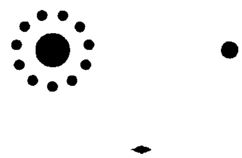
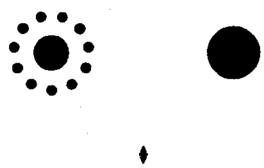
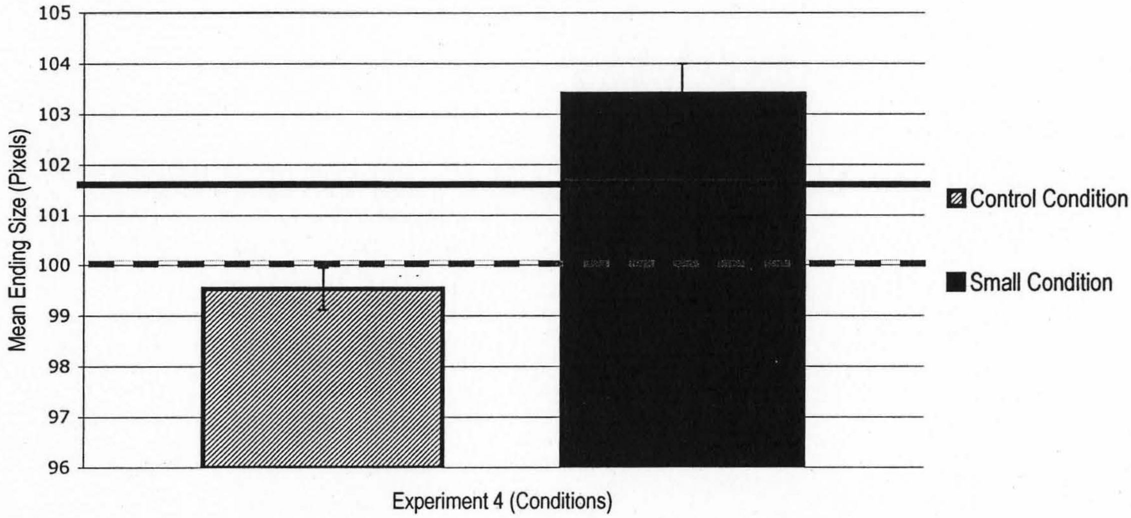
	Conditions in Experiment Four	
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target	
Trials	***Left Central Target – Isolated***	***Left Central Target – Small Annuli***
Increase *Right Target Starting Size = 1.50 cm*	*Horizontal Slider Right to Increase / Left to Decrease*	
		
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider Down to Increase/ Up to Decrease*	
		

Figure 2


105
104
103
102
101
100
99
98
97
96
Mean Ending Size (Pixels)
Experiment 4 (Conditions)
Control Condition
Small Condition

EXPERIMENT FIVE

5.0 Introduction

From Experiment 4, it was found that the SA condition was not strong enough to elicit a hysteretic pattern in perceptual error biases. One possibility for these results is that hysteresis effects do require both illusionary conditions to be presented in the stimulus set, as demonstrated in Experiment 2 and Experiment 3.

The results of Experiment 4 results suggest that the hysteretic shift found in Experiment 2 can either be attributed to either the presence of the LA condition or that the observed hysteresis effects require both illusionary extremes.

Therefore, Experiment 5 was conducted in which the SA condition was eliminated. The purpose of Experiment 5 was to investigate whether or not the LA condition will be strong enough to elicit hysteresis effects when only presented in combination with the control condition. It was anticipated that an adaptation effect should result even in an environment with a single illusionary influence, where the LA condition bias will move towards 100 pixel value and the control condition bias will decrease significantly from its bias in Experiment 1A. It was also anticipated that the LA condition will be strong enough elicit a hysteretic shift in the adaptation effects with the control condition.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 19.2 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as was employed in Experiment 2.

Procedure

The task was identical to Experiment 2 except that in this case, the left side target circles appeared as ; 1) an Isolated Condition, or 2) a Large Annuli Condition in which the left target was surrounded with 5 large circular arrays of annuli (see Figure 1).

Again, the experiment was a 2 (condition) by 4 (starting size) by 2 (direction) design. In total, there were 2 different left target conditions with 4 starting sizes for each condition, tested 10 times randomly for a total of 80 trials.

Experimental Design and Data Analysis

Identical data analyses were conducted on Experiment 5 as were employed in Experiment 4.

Results

A main effect was evident for Condition, $F(1,10)= 5.40$; $p.<0.05$, with post-hoc analysis confirming that the control condition of 98.51 pixels (underestimated by 1.49 pixels) was significantly different from the LA condition of 97.31 pixels (underestimated by 2.69 pixels) (see Figure 2).

A main effect for Starting Size, $F(3, 30)= 5.78$; $p.<0.01$, was also evident with post-hoc analysis confirming that the small starting sizes (50% and 75%) were significantly different from the largest starting size (150%) (see Figure 3). Additionally, post-hoc analysis confirmed that the two increasing starting sizes were not significantly different from each other. As well, the two decreasing starting sizes were also not significantly different from each other. On average the mean of the two increasing starting sizes were significantly different from the mean of the two decreasing starting sizes (Average error on "increase" trials = -2.87 pixels; average error on "decrease" trials = -1.31). Overall the tendency across conditions was to underestimate the right isolated target by 2.09 pixels.

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 98.51 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation was not significantly different from 100. However, the mean target ending size of the LA condition of 97.31 pixels was significantly different from 100 (see Table 1).

Trial Order Analysis

No main effects were evident in the trial order analysis of variance. However, the effect for the Current Condition, $F(1,10)= 4.66$; $p.=.0562$ was very close to significance. The post-hoc analysis confirmed that that the control condition (98.48 pixels) was not significantly different from the LA condition (97.31 pixels).

Between-Experiment Analysis (Experiment 5 versus Experiment 2)

The purpose behind conducting a between-experiment analysis between Experiment 5 and Experiment 2 was to investigate if hysteresis effects are mediated by the combination of both illusionary annuli extremes. It was anticipated that a between-experiment effect will result, suggesting that the control and LA conditions in Experiment 5 were differentially perceived from those conditions in Experiment 2 thereby suggesting that hysteresis effects were differentially mediated when compared to Experiment 2.

Results

A main effect for Condition, $F(1, 20)=12.52$; $p.<0.01$, was evident with post- hoc confirming that the control condition of 98.35 pixels (underestimated by 1.65 pixels) was significantly different from the LA condition of 96.83 pixels (underestimated by 3.17 pixels).

A main effect for Starting Size, $F(3, 60) = 11.65$; $p.<0.00001$, with post-hoc analysis was also evident confirming that the 50% and 75% starting sizes were different from both of the 125% and 150% staring sizes. The larger starting sizes were more accurate then the smaller starting sizes, when compared to the 100 pixel comparator value. As well, a main effect for Direction, $F(1, 20) = 9.26$; $p.<0.01$, confirmed that the vertical slider was significantly different of 97.81 pixels and more accurate then the horizontal slider of 97.38 pixels.

Also a Condition by Starting Size interaction was revealed, $F(3, 60) = 4.76$; $p.<0.01$, with post-hoc analysis confirming that across group the increasing starting sizes were significantly different from the decreasing starting sizes only in the LA illusionary condition. Starting sizes were not significantly different within the control condition.

Post Hoc Analysis (Experiment 5 and Experiment 1 and 2)

When the mean target ending size of the control condition in Experiment 5 of 98.51 pixels was compared against the comparable condition in Experiment 1A (101.29 pixels) and Experiment 2 (98.185 pixels), it was confirmed that the control mean target ending size in Experiment 5 was significantly different from Experiment 1A but not from Experiment 2. When mean target ending size of the LA condition in Experiment 5 of 97.31 pixels was compared against the comparable condition in Experiment 1B (97.1 pixels) and Experiment 2 (96.37 pixels), it was confirmed that the mean target ending size in Experiment 5 was not significantly different from either underestimation in Experiment 1B or 2 (see Table 1).

Discussion

The main effect for condition was still evident, wherein the LA illusionary condition was perceived to be smaller then the control condition. The misperception of the LA condition was not significantly different from LA misperceptions found in Experiment 1B or Experiment 2. The LA condition does have a significant effect on the control condition by decreasing the overall perceptual error when compared to control condition in Experiment 1A. Therefore, signs of significant adaptation effects are revealed in these results. However, a between-experiment analysis also revealed that there was not a difference between Experiment 2 and Experiment 5.

Conclusion

Between-experiment analysis demonstrated that misperceptions of the control and LA conditions were the same regardless of whether or not the SA condition was present. As well, there was no hysteretic effect in the perceptual error adaptation patterns. This would have been noticed if perceptual error undershoot bias of the LA in Experiment 1B further intensified. Instead the LA regressed towards the 100 pixel value. These results then at least partially support the idea that hysteresis effects do require both illusionary conditions to be present in the stimulus set. Also, there is a significant difference between the perceptual biases of LA condition in Experiment 1B and the perceptual biases of the LA condition in Experiment 5, however, it also seems that the LA when only presented on its own, is not strong enough to elicit a hysteresis effect.

Table 1.

Perceptual judgment errors in Experiment 5 relative to the 100 pixel comparator target, isolated conditions from Experiment 1, and comparable conditions in Experiment 2.

	Perceptual Judgment Errors in Experiment 5	
	Control Condition 98.51 pixels	Large Annuli Condition 97.31 pixels
Comparator Target 100 pixels	=	≠
Experiment 1A 101.29 pixels	≠	
Experiment 1B 97.1 pixels		=
Comparable Experiment 2 Condition	= (Control 98.19 pixels)	= (Large 96.37 pixels)

Figure Captions: Experiment 5

Figure 1. Illustration of the experimental test conditions employed in Experiment 5 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixel comparator target and the mean undershoot bias of 2.09 pixels

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the100 pixel comparator target and the mean undershoot bias of 2.09 pixels.

Figure 1

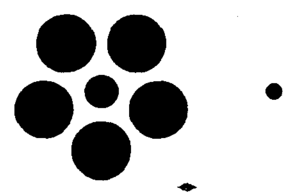
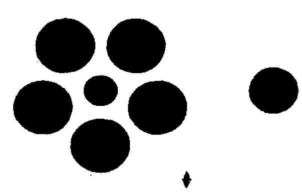
	Conditions in Experiment Five	
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target	
Trials	***Left Central Target – Isolated***	***Left Central Target – Large Annuli***
Increase *Right Target Starting Size = 1.50 cm*	*Horizontal Slider* *Right to Increase / Left to Decrease*	
		
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider* *Down to Increase/ Up to Decrease*	
		

Figure 2

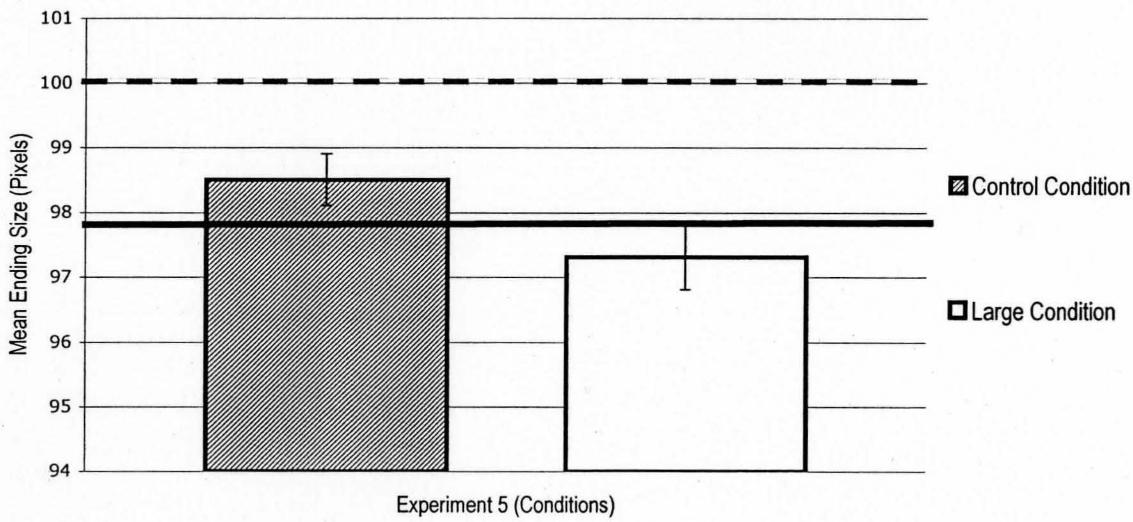
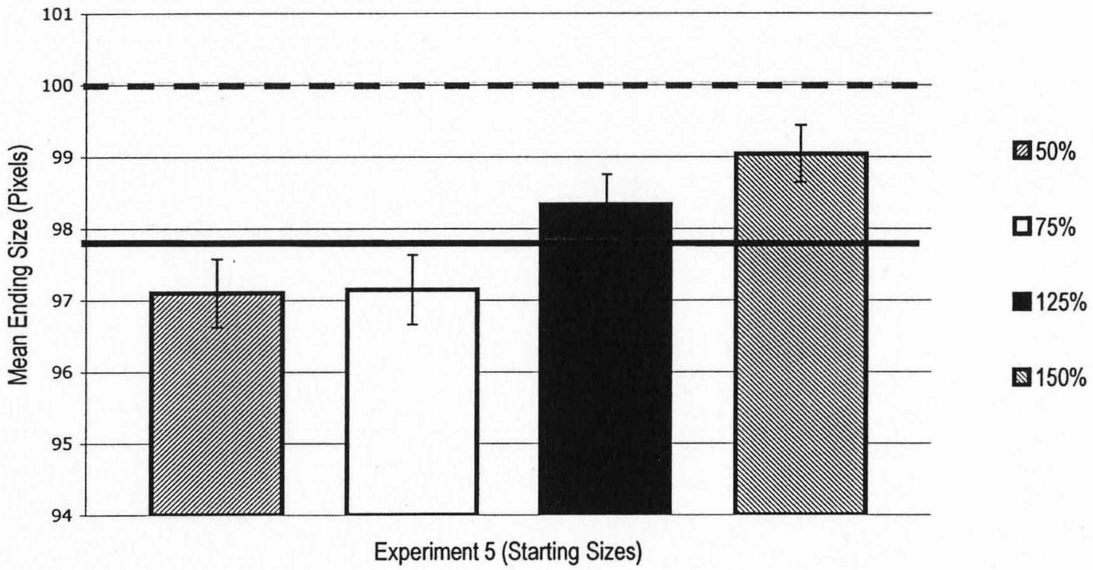

101
100
99
98
97
96
95
94
Mean Ending Size (Pixels)
Experiment 5 (Conditions)
Control Condition
Large Condition

Figure 3


101
100
99
98
97
96
95
94
Mean Ending Size (Pixels)
Experiment 5 (Starting Sizes)
50%
75%
125%
150%

SUMMARY: EXPERIMENT 4 AND 5

Overall, Experiment 4 and Experiment 5 suggest that the hysteresis effects observed in Experiment 2 and Experiment 3, seem to require both illusionary conditions to be present. Neither the LA or the SA condition produced the hysteretic perceptual patterns alone with the control condition.

Adaptation perceptual patterns were seen in both Experiment 4 and 5 however, adaptation effects of the control condition were only observed in combination with the LA condition thus supporting the idea that the LA condition delivers a more salient illusionary effect, and that the illusionary conditions were not created equally.

Overall, removing one contributing annuli stimulus out of the annuli stimulus array still elicits adaptation pattern effects between those remaining stimuli, however the effect is not as pronounced compared to adaptation effects in Experiment 2. The only statistically significant adaptation effects on the control condition are present in Experiment 5.

There was no difference between experiment 4 and 5 however, when looking at the overall perceptual error of each condition, patterns indicate that neither LA or SA conditions produced hysteretic effects on their own when only presented with the control condition. Therefore, it seems plausible that both illusionary conditions in the same stimulus set are required for adaptation effects to be present.

EXPERIMENT SIX

6.0 Introduction

In all experiments thus far a potential stimulus-response confound exists. This confound is present in 4 different starting sizes which require increasing or decreasing size adjustments. In Experiment 2, the experimental design was constructed in such a way that there were two increasing and two decreasing target disc starting sizes which in turn required adjustment manipulations on both a horizontal and vertical slider. In Experiment 2 starting size was revealed as a main effect. Post-hoc analysis confirmed that the two increasing starting sizes were not significantly different from each other, nor were the two decreasing starting sizes however, on average, the mean of the two increasing starting sizes were significantly different from the mean two decreasing starting sizes (Average error on "increase" trials = -1.80 pixels; average error on "decrease" trials = -0.77).

This starting size effect is confounded by: 1) the requirement of adjusting actual physical sizes (as described by the range effect) and 2) the fact that these physical size adjustments have associated slider movement manipulations (to increase a small starting size, a right or downward slider manipulation is required). Therefore, when starting size is revealed as a main effect, the questions that are raised are: What is actual influential aspect in this main effect? Is it the actual increasing/decreasing of the target (range effect) or the moving towards/moving away from the illusion (visual attention) based on slider manipulations?

In Experiment 2 Direction of Slider was also revealed as a main effect, suggesting that the horizontal slider was significantly less accurate then the vertical slider. Of primary concern was that the horizontal slider, in which a larger starting size (which requires a make decreasing slider movement) required a left movement on the horizontal slide. This left slider movement can be seen as making a movement towards or into the illusion. Therefore, making a left slider movement could have had the additional effect of directing visual attention toward the illusion, and thus making the illusion more effective overall. Thus, this starting size confound may not involve the actual physical size of the comparator target but rather be the result of required movement actions to adjust such starting size with the concomitant shift of attentional focus associated with the slider movement influencing the recurring starting size effects.

Based on recent research focused on spatial attention, there is reason to believe that the required slider manipulation could have guided visuospatial attention, thereby making it the influencing factor in the starting size effect. Sturm, Schmenk, Fimm, Specht, Weis, Thron, and Willmes (2005) acknowledged that there are areas within the brain that seem to be important for spatial attention. Therefore, it is entirely possible that the horizontal associated slider movements could have evoked a stronger focused visuospatial attention bias and effect overall misperception results.

As well, when investigating spatial attention it is important to acknowledged the neural mechanisms involved in spatial attention. Research suggests that spatial selective attention can alter processing in perceptual areas (Desimone & Duncan, 1995; and Posner & Petersen, 1990). Therefore, it could be suggested that the horizontal slider could potentially evoke spatial attention more so and thus result in altering perceptual experiences, especially of illusionary stimuli.

Further research has suggested that the hemispheric attention systems have competing biases that direct attention to the contralateral space. It has been suggested that the left hemisphere has a stronger and/or more focused intrinsic bias then the right hemisphere (Kinsbourne, 1993). The study conducted by Spence and Banich (2005) investigated the control of spatial attention and the potential influence by hemispheric utilization bias (HUB). HUB is an individual characteristic response bias in which one hemisphere is utilized more so than the other (Levy, Heller, Banich, & Burton, 1983). Spencer and Banich highlight the issue that hemispheric utilization bias is a type of internal competition between visual hemispheres in current neural research, that has not been fully researched. It has been suggested in previous studies (Kim & Levine, 1991, and 1992; and Kim, Levine, & Kertesz, 1990) that the when dealing with laterality tasks, between-subject variance can be attributed to HUB. Therefore, the characteristic biases that individuals possess for consistently utilizing one hemisphere more than the other for processing information, could potentially become a significant source of error faced in many studies. Spencer and Banich (2005) predicted that Left Hemisphere (LH) – biased individuals would show a strong rightward attentional bias, therefore finding it very challenging to focus on stimuli that are located in the left visual field. They concluded that HUB can enhance a hemisphere's contralateral attentional bias and provided evidence that HUB definitely influences visuospatial attention. This is an interesting point to note, such that in any experiment it is hard to control for such a variable and that this variable might be responsible for all the controversial evidence when dissociating the ventral versus dorsal visual streams and their relative contributions to perception and action.

Therefore, the purpose of this study was to further investigate the potentially confounding aspects within the starting size. The response dimensions were switched such that increasing response movements required slider movements towards the illusion whereas, decreasing responses required slider movements away from illusion. It was anticipated that if visual attention associated with required slider movements is not influential to the recurring starting size effect (suggesting rather it is the physical increasing/decreasing comparator target manipulation issue) an identical starting size pattern will remain as in Experiment 2. However, if it is the visual attention associated with required slider movements (movement towards versus movements away from the illusion) that is the more influential variable, then the starting size pattern results will be in the opposite direction as in Experiment 2 (corresponding to the new slider direction).

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 18.5 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus utilized as employed in Experiment 2.

Procedure

The task was identical to Experiment 2, with the exception that both the horizontal and vertical sliders were switched. Therefore, now in order to increase the comparator target using the horizontal slider, a movement to the left was required. Conversely, a movement to the right on the horizontal slider would decrease the comparator target's size. On the vertical slider, to increase the size of the comparator target required an upward movement, whereas to decrease a downward movement was required (see Figure 1).

Identical data analyses were conducted on Experiment 6 as were employed in Experiment 2. Also, two individual 3 (condition) x 4 (starting size) repeated measures analyses of variance were conducted between Experiment 6 and Experiment 2, on the perceptually judged physical manipulations made using only the horizontal or vertical sliders.

Results

A main effect for Condition, $F(2, 20) = 9.19$; $p.<0.01$, was evident with post-hoc analysis confirming that the control condition of 97.10 pixels (underestimated by 2.90 pixels) was not significantly different from the LA condition of 96.47 pixels (underestimated by 3.53 pixels) but was significantly different from the SA condition of 101.32 pixels (overestimated by 1.32 pixels). The LA condition was significantly different however, from the SA condition (see Figure 2).

A main effect for Starting Size, $F(3, 30) = 6.37$; $p.<0.01$, was evident with post-hoc analysis confirming that the two increasing starting sizes were not significantly different from each other. However the two decreasing starting sizes were significantly different from each other (see Figure 3). On average, the mean two increasing starting sizes were significantly different from the mean of the two decreasing starting sizes (Average error on "increase" trials = -2.29 pixels; average error on "decrease" trials = -1.12). Overall, the main tendency regardless of condition or starting size was to underestimate the right comparator target by 1.71 pixels.

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 97.09 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation in this experiment was significantly different from 100. The mean target ending size when under the LA condition of 97.47 pixels was significantly different from 100. However, the SA condition of 101.32 pixels was not significantly different from 100 (see Table 1).

Trial Order Analysis

A main effect was revealed for the Current Condition, $F(2, 20) = 8.68$; $p. < 0.01$. Post-hoc analysis revealed that the control condition (97.07 pixels) was significantly different from the SA condition (101.30 pixels) but not from the LA condition (96.58 pixels). Also, post-hoc analysis revealed that the SA condition was significantly different from both the LA and control conditions.

Between-Experiment Analysis (Experiment 6 versus Experiment 2)

The purpose behind conducting a between-experiment analysis between Experiment 6 and Experiment 2 was to investigate and compare starting size effects and patterns under opposite required movement manipulations. It was anticipated that if visual attention associated with required slider movements is influential to the recurring starting size effect, a between-experiment effect will be evident, thus corresponding to the new slider direction. However, if it is rather the physical increasing/decreasing manipulations, no between-experiment factor will arise between Experiment 6 and Experiment 2.

Results

A main effect for Condition, $F(2, 40) = 28.48$; $p.<0.00001$, was evident with post-hoc analysis confirming that the SA condition (101.45 pixels) was significantly different from both the control (97.64 pixels) and LA conditions (96.42 pixels). However, the control and LA conditions were not statistically different. A main effect for Starting Size, $F(3, 60) = 12.57$; $p.<0.00001$, was also revealed confirming that the larger starting sizes were more accurate then the smaller starting sizes.

Between- Experiment Analysis: Horizontal Slider (Exp. 6 versus Exp.2)

A main effect for Condition, $F(2, 40) = 30.41$; $p.<0.00001$, was revealed with post-hoc analysis confirming that the SA condition (101.48 pixels) was significantly different from both the control (97.44 pixels) and LA conditions (96.43 pixels). However, again the control and LA conditions were not statistically different. A main effect for Starting Size, $F(3, 60) = 7.31$; $p.<0.001$, was also evident.

Between- Experiment Analysis: Vertical Slider (Exp. 6 versus Exp. 2)

A main effect for Condition, $F(2, 40) = 23.15$; $p.<0.00001$, was evident with post-hoc analysis confirming that the SA condition (101.42 pixels) was significantly different from both the control (97.84 pixels) and LA conditions

(96.41 pixels). However, the control and LA conditions were not statistically different. A main effect for Starting Size, $F(3, 60) = 12.36$; $p.<0.00001$, was also evident.

Post Hoc Analysis (Experiment 6 versus Experiment Two)

The mean target ending sizes were not significantly different between Experiment 2 and Experiment 6. (Control Condition: Experiment 2 = 98.19 pixels, Experiment 6 = 97.09 pixels; LA condition: Experiment 2 = 96.37 pixels, Experiment 6 = 96.47 pixels; SA condition: Experiment 2 = 101.59 pixels, Experiment 6 = 101.32 pixels) (see Table 1).

Discussion

Initially there was reason to believe that the sliders employed in this experimental protocol could have influentially guided visuospatial attention. (see Desimone and Duncan, 1995; Posner and Petersen, 1990; Sturm et al., 2005). However, the between-experiment analysis revealed that all 3 conditions (control, LA, and SA) in Experiment 6 were not significantly different from their comparable conditions in Experiment 2. Therefore, similar perceptual effects were demonstrated in Experiment 6, as were found in Experiment 2. The absence of any group effect or interaction with group between Experiment 6 and Experiment 2, suggests that the attentional issue (ie. visual attention shifting with the direction in which the slider must be manipulated) does not have an influential influence on the overall misperceptions between Experiment 6 and 2.

No between group effects or interactions were evident when analyzing space and movement response compatibility within Experiment 6. Results suggest that that space compatibility and movement response compatibility are not influential factors in the overall misperceptions found in Experiment 6, in both horizontal and vertical slider directions.

It is to be noted that in this experiment the control condition was not significantly different from the LA, in which both conditions undershot the 100 pixel target significantly. This result suggests some degree of adaptation and that once again the LA condition seems to be a salient illusionary stimulus.

Starting size effect was again evident wherein the larger starting sizes were more accurate when compared to 100 pixel target value. However when starting sizes were compared to the overall undershoot based on all conditions, the range effect theory is present with respect to starting size origin. Starting size pattern was similar to the pattern found in Experiment 2, therefore suggesting that visual attention is not mediated by the starting size and slider directions. The range effect is present but not as cleanly demonstrated as in Experiment 3.

A notable limitation to this thesis is that hemispheric utilization bias (HUB) of each participant was not known. Numerous studies have investigated the control of spatial attention and the potential influence by hemispheric utilization bias (Kim & Levine, 1991 and 1992; Kim, Levine, & Kertesz, 1990; and Spence & Banich, 2005). HUB is one potential issue that could have influence illusionary misperceptions by play a crucial role in visuospatial attention.

Conclusion

The starting size main effect was maintained in Experiment 6 even when sliders were switched therefore suggesting that visual attention associated with movement direction (moving towards/moving away) relative to location of illusion is not particularly influential on the overall misperceptions found in Experiment 2.Due to the fact that starting size effect was maintained, it seems that increasing/ decreasing the actual physical target size, may be the possible factor behind the significant starting size. The consistent starting size main effects, can be explained by the range effect, as explained in Experiment 2.

Overall, Experiment 6 suggests that visual attention guided by slider direction of required manipulation movement is not a mediating factor with respect to the reoccurring starting size main effect.

Table 1.

Perceptual judgment errors in Experiment 6 relative to the 100 pixel comparator target and comparable conditions in Experiment 2.

	Perceptual Judgment Errors in Experiment 6		
	Control Condition 97.09 pixels	Large Annuli Condition 96.47 pixels	Small Annuli Condition 101.32 pixels
Comparator Target 100 pixels	≠	≠	=
Comparable Experiment 2 Condition	= (Control 98.19 pixels)	= (Large 96.37 pixels)	= (Small 101.59 pixels)

Figure Captions: Experiment 6

Figure 1. Illustration of the experimental test conditions employed in Experiment 6 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixels comparator target and the mean undershoot bias of 1.7 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the100 pixels comparator target and the mean undershoot bias of 1.7 pixels.

Figure 1

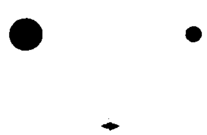
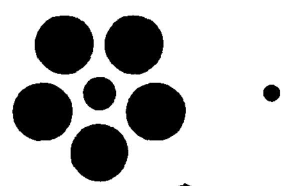
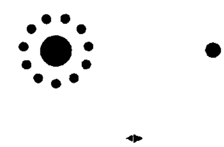
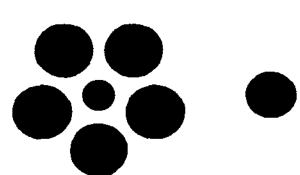
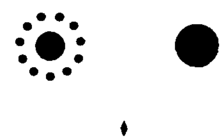
	Conditions in Experiment Six		
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target		
Trials	***Left Central Target – Isolated***	***Left Central Target – Large Annuli***	***Left Central Target – Small Annuli***
Increase *Right Target Starting Size = 1.50 cm*	*Horizontal Slider* *Right to Decrease / Left to Increase*		
			
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider* *Down to Decrease / Up to Increase*		
			

Figure 2

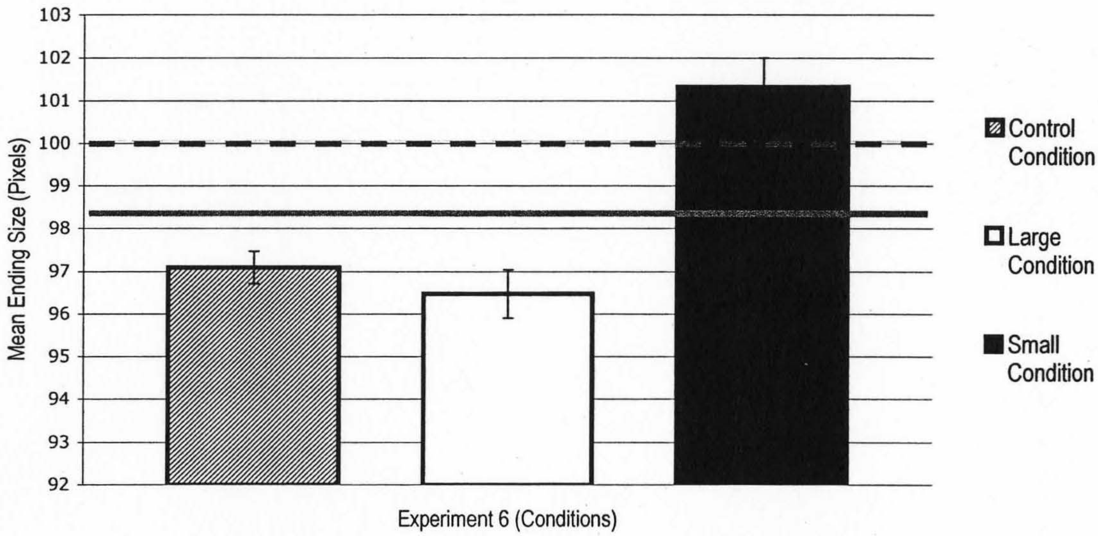
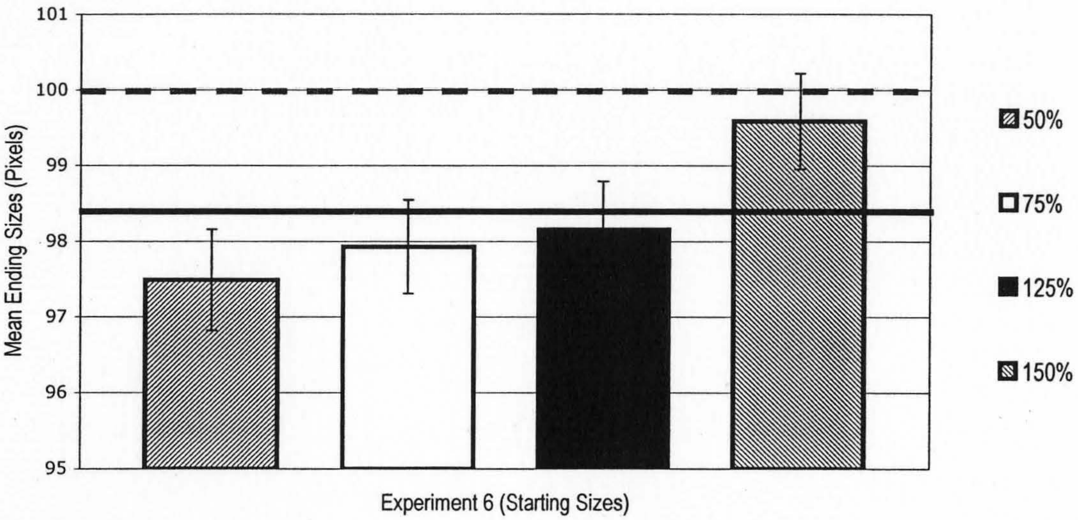

103
102
101
100
99
98
97
96
95
94
93
92
Mean Ending Size (Pixels)
Experiment 6 (Conditions)
Control Condition
Large Condition
Small Condition

Figure 3


101
100
99
98
97
96
95
Mean Ending Sizes (Pixels)
Experiment 6 (Starting Sizes)
50%
75%
125%
150%

EXPERIMENT SEVEN

7.0 Introduction

An additional potential problem with Experiment 2 is that the illusion always appears in the left visual space (i.e. the stimulus events always appearing in contralateral space). Related to this, the manipulations are always occurring on the right side (i.e. response dimensions always occurring in ipsilateral space). Previous research has suggested that where a target is situated within its environment might be influential on overall misperceptions.

McAuliffe and Knowlton (2001) suggest that the specialization roles of object identification are unclear with respect to the left and right hemispheres. Hubel and Wiesel (1959, 1962) have shown that visual processing of information occurs in both hemispheres in a similar fashion, however it has to be noted that they also showed that each hemisphere processes visual information from a different half of visual space. It has been suggested by numerous researchers that faster processing in a particular hemifield, could be considered suggestive evidence for specialization in that contralateral hemisphere (Biederman & Cooper, 1991; Hellige & Cowin, 1996; Hellige, Cowin, & Eng, 1995; Hellige & Scott, 1997; Leehey & Cahn, 1979; Levine & Banich, 1982; Marsolek, 1999; Polich, 1978; Sergent & Hellige, 1986). Neurophysiological studies by Layman and Greene (1988) and Warrington & Taylor (1973) suggest that the right hemisphere (RH) is faster in identifying objects presented in non-typical views (depth and / picture plane rotations). Because it is suggested that the RH is specialized for visuospatial processing, objects might be identified faster in the RH/LVF because the RH can construct a perceptual representation faster than the LH/RVF. McAuliffe and Knowlton (2001) study suggests that the RH is specialized in object identification.

Acknowledging these studies, it seems possible that the RH/LVF could also be specialized with regard to object size-matching. Therefore, in Experiment Seven the illusionary stimuli which originally were presented in the LVF(in all previous experiments) were now switch to RVF to see if there was any physical manipulation differences, as seen in perceptual errors since there is reason to believe that laterality might be an influential aspect that may contribute to the overall misperceptions found in Experiment 2. Therefore, in this study, the purpose was to investigate the cross-axis laterality influence of stimulus events on the overall misperceptions found in Experiment 2. Experiment 7 addresses laterality issue by rerunning Experiment 2, but simply moving the stimulus events into the ipsilateral space (right side of the computer monitor) from its original contralateral space as in Experiment 2 (and all previous experiments). If laterality is a contributing factor to the overall misperceptions found in Experiment 2, a between-experiment analysis of variance between Experiment 7 and Experiment 2 should reveal a main effect for group.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 18.5 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as was employed in Experiment 2.

Procedure

The task was identical to Experiment 2, except the side in space in which participants had to manipulate the physical size of the isolated circle (target disc) to perceptually match the physical size of a target circle (comparator target) was switched. Therefore, the target disc that participants had to manipulate was now on the left side of the computer monitor, with the 3 different annuli conditions occurring on the right side of the monitor. All aspect such as starting size, sensitivity and the dimensions of constructed annuli arrays from Experiment 2 were maintained (see Figure 1). In total there were 3 different right side conditions (Isolated, LA, and SA Condition), with 4 different starting sizes for each condition tested 10 times randomly for a total of 120 trials.

Experimental Design and Data Analysis

Identical data analyses were conducted on Experiment 7 as were employed in Experiment 2.

Results

A main effect for Condition, $F(2, 20) = 20.1$; $p.<0.0001$, was evident with post-hoc analysis confirming that the control condition of 99.35 pixels (underestimated by 0.65 pixels) was not significantly different from the LA condition of 97.82 pixels (underestimated by 2.12 pixels), but was significantly different from the SA condition of 103.58 pixels (overestimated by 3.58 pixels). Further post-hoc analysis confirmed that the LA condition was significantly different from the SA condition (see Figure 2).

A main effect for Starting Size, $F(3, 30) = 4.20$; $p.<0.05$, was also evident with post-hoc analysis confirming that significant differences lie between the smallest starting sizes (50% and 75%) and the largest starting size (150%). Further post-hoc analysis confirmed that the two increasing starting sizes were not significantly different from each other, nor were the two decreasing starting sizes significantly different from each other. On average, the mean of the two increasing starting sizes were significantly different from the mean of the two decreasing starting sizes (Average error on "increase" trials = -0.42 pixels; average error on "decrease" trials= 0.92 pixels) (see Figure 3). Overall, the main tendency regardless of condition or starting size was to perceptually overestimate the left isolated comparator target by 0.25 pixels.

A Condition by Starting Size interaction also occurred, $F(6, 60) = 3.28$, $p.<0.01$. Post-hoc analysis confirmed that differences not only arose between conditions across the 4 starting sizes but also there were significant differences within the LA and SA conditions across the 4 starting sizes. However, there were no significant differences between the 4 starting sizes within the control condition. Further post-hoc analysis confirmed that when comparing the mean of the increasing starting sizes to the mean of the decreasing starting sizes the control condition was the only one in which the means were not significantly different. Additionally, when comparing the starting sizes across conditions, post-hoc analysis confirmed that the increasing starting were significantly different. However, the decreasing starting when compared across condition, it was found that the control and LA conditions were not significantly different, but LA and control conditions were significantly different from the small starting sizes.

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 99.35 pixels was compared against the comparator value of 100 pixels, it was confirmed that the underestimation in this experiment was not significantly different from 100. The mean target ending size when under the LA condition of 97.82 pixels was not significantly different from 100. However, the SA condition of 103.58 pixels was significantly different from 100 (see Table 1).

Trial Order Analysis

A main effect was revealed for the Current Condition $F(2, 20) = 19.33$; $p.<0.0001$. Post-hoc analysis revealed that the control condition (99.31) was not significantly different from the LA condition (97.78 pixels) but was significantly different from the SA condition (103.49 pixels). The SA condition was significantly different from both the LA and control conditions.

As well, a Current Condition by Previous Condition interaction resulted $F(4, 40) = 2.69$; $p.<0.05$. Post hoc analysis revealed that there were no significant differences within each current condition. Rather, the significant differences arose when comparing each current condition across the 3 previous conditions (see Figure 4).

Between-Experiment Analysis (Experiment 7 versus Experiment 2)

Results

A main effect for Condition, $F(2, 40) = 48.38$; $p.<0.00001$, was evident with post-hoc analysis confirming that all 3 conditions were significantly different from one another.

A main effect for Starting Size, $F(3, 60) = 9.49$; $p.<0.0001$. Where the larger starting sizes was more accurate then the smaller starting sizes when compared to 100pixel target. A main effect for Direction $F(1, 20) = 7.5$; $p.<0.05$, was also revealed.

As well, a Condition by Starting Size interaction $F(6, 120) = 4.01$; $p.<0.01$, was revealed with post-hoc analysis confirming that differences not only arose between conditions across the 4 starting sizes but also there were significant differences within the LA and SA conditions across the 4 starting sizes. However, there were no significant differences between the 4 starting sizes within the control condition. Post-hoc analysis confirmed that when comparing the increasing starting sizes to the decreasing starting sizes the control condition, was the only one in which the starting sizes were not significantly different.

Post Hoc Analysis (Experiment 7 versus Experiment 2)

The mean target ending sizes were not significantly different between Experiment 2 and Experiment 7. (Control Condition: Experiment 2 = 98.19 pixels, Experiment 7 = 99.35 pixels; LA condition: Experiment 2 = 96.37 pixels, Experiment 7 = 97.82 pixels; SA condition: Experiment 2 = 101.59 pixels, Experiment 7 = 103.58 pixels) (see Table 1).

Discussion

Previous studies have shown that where a target is situated within its environment might be influential on overall misperceptions (Layman, & Greene, 1988; McAuliffe, & Knowlton 2001; and Warrington, & Taylor 1973). However, no significant differences between Experiment 7 and Experiment 2 resulted, as evident in the lack of between- experiment effects. Therefore, the side in space in which the illusion resides has little consequence on overall misperceptions found.

The results of this experiment suggest that the same starting size effect pattern was maintained even when side of illusion was switched. The starting size pattern was identical to previous starting size patterns, and demonstrated the range effect as cleanly as seen in Experiment 3 when compared to both the 100 pixel target and the overall overshoot bias. This is the first time that the range effect has been shown with respect to the 100 pixel target. The fact that the starting size main effect is present even though the illusionary present is switched into the ipsilateral visual space suggests then that the physical size manipulations (increasing or decreasing manipulations) are the influential variable in the start size effects. Therefore, results show again that visual attention guided by movement direction (moving towards versus moving away) relative to the location of the illusion is not the influential variable confounded within the starting size main effects. These results further support the results of Experiment 6. As well, Experiment 7 also demonstrated adaptation effects, similar to those seen in Experiment 2.

Conclusion

Laterality is not a mediating factor as demonstrated in the absence of the between- experiment effect when analyzing Experiment 7 and Experiment 2. Therefore, manipulating target sizes in the contralateral visual space does not seem to have an influential effect on the overall misperceptions found in Experiment 7. As well starting size pattern remained even when the illusionary influence was place in the ipsilateral visual space, demonstrating a clean range effect pattern. The presence of starting size effect suggests that again the increasing / decreasing confounding variable seems to be influential variable in starting size.

Table 1.

Perceptual judgment errors in Experiment 7 relative to the 100 pixel comparator target and comparable conditions in Experiment 2.

	Perceptual Judgment Errors in Experiment 7		
	Control Condition 99.35 pixels	Large Annuli Condition 97.82 pixels	Small Annuli Condition 103.58 pixels
Comparator Target 100 pixels	=	=	≠
Comparable Experiment 2 Condition	= (Control 98.19 pixels)	= (Large 96.37 pixels)	= (Small 101.59 pixels)

Figure Captions: Experiment 7

Figure 1. Illustration of the experimental test conditions employed in Experiment 7 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixel comparator target and the mean overshoot bias of 0.25 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the100 pixels comparator target and the mean overshoot bias of 0.25 pixels.

Figure 4. Mean ending size (pixels) and standard error as a function trial order against the 100 pixel comparator target.

Figure 1

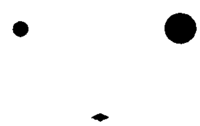
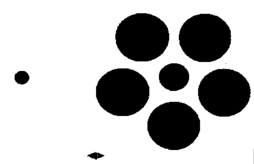
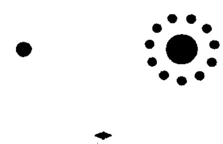
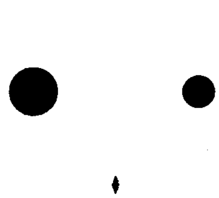
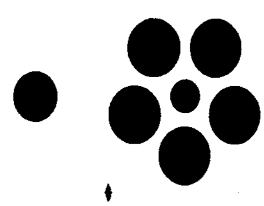
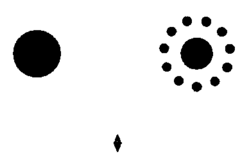
	Conditions in Experiment Seven		
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target		
Trials	***Left Central Target – Isolated***	***Left Central Target – Large Annuli***	***Left Central Target – Small Annuli***
Increase *Right Target Starting Size = 1.50 cm*	*Horizontal Slider Right to Increase / Left to Decrease*		
			
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider Down to Increase/ Up to Decrease*		
			

Figure 2

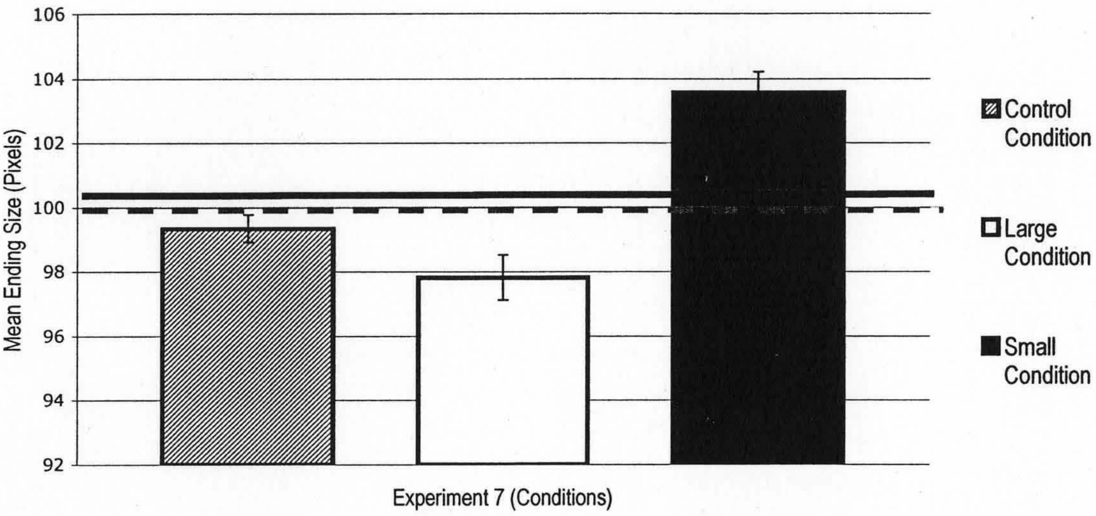

106
104
102
100
98
96
94
92
Mean Ending Size (Pixels)
Experiment 7 (Conditions)
Control Condition
Large Condition
Small Condition

Figure 3

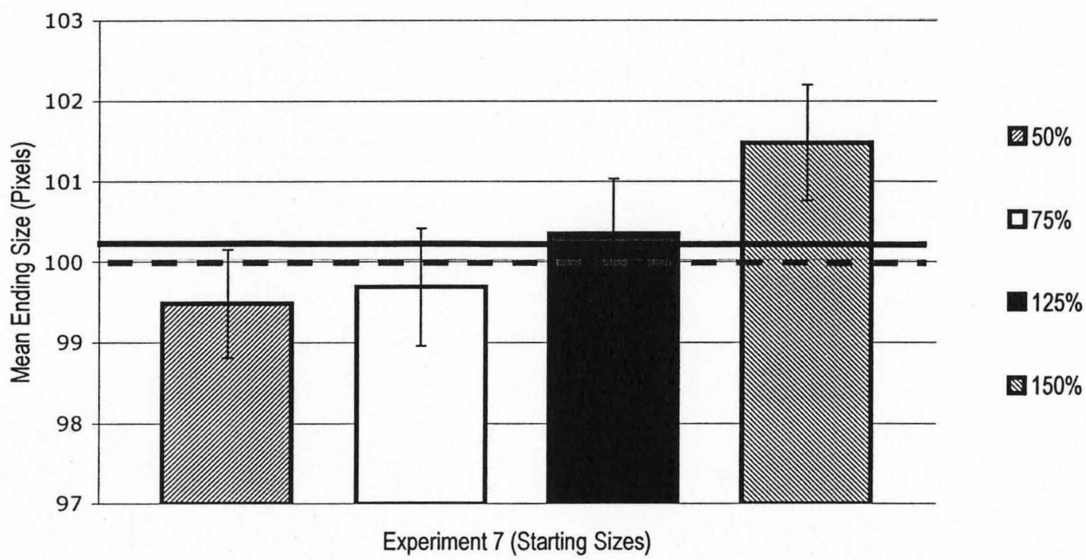
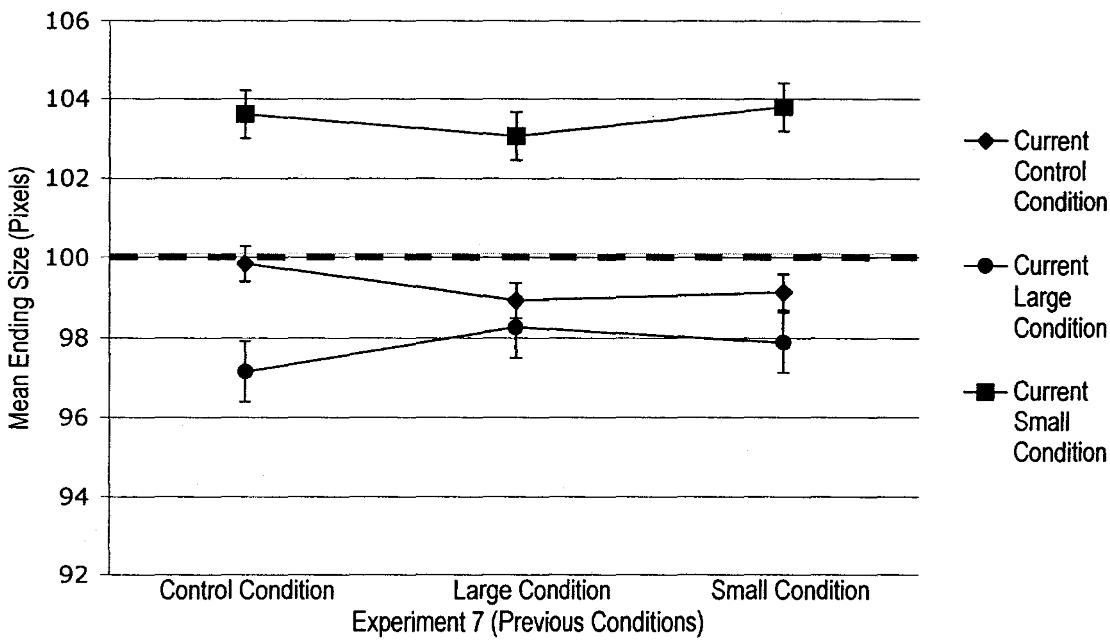

103
102
101
100
99
98
97
Mean Ending Size (Pixels)
Experiment 7 (Starting Sizes)
50%
75%
125%
150%

Figure 4


106
104
102
100
98
96
94
92
Mean Ending Size (Pixels)
Control Condition
Large Condition
Small Condition
Experiment 7 (Previous Conditions)
Current Control Condition
Current Large Condition
Current Small Condition

EXPERIMENT EIGHT

8.0 Introduction

In order to maintain and ensure that both laterality of illusionary stimulus and the direction of visual attention as guided by the slider, are not influential to the overall misperceptions found in Experiment 2, one final manipulation was necessary. In this experiment the illusion remained in the ipsilateral space but the slider direction (make bigger/make smaller) was reversed from Experiment 2, corresponding instead to slider directions in Experiment 6. Both of these manipulations result in essentially, a reversed mirror image of experiment 2.

The purpose of this study was, therefore, to further investigate the findings of Experiment 6 and Experiment 7. It was anticipated that there would be no significant difference between Experiment 7 and 8, where the starting size results of Experiment 8 will be similar to the starting size results found within Experiment 2 and Experiment 6. As well, it was also anticipated that there would be no significant difference between Experiment 6 and 8, suggesting that laterality does not play a crucial role in overall perceptual errors found in Experiment 2.

Method

Participants

Eleven right-handed participants (5 male and 6 female; mean age = 19.9 years) with normal or corrected-to-normal vision participated in the experiment. All participants used their right hands when making physical manipulations and were all naïve to the purpose of the study. All participants gave written, informed consent to participate in the study in accordance with the guideline for ethics from McMaster University Research Ethics Board (MREB).

Apparatus

The identical apparatus was utilized as was Employed in Experiment 7.

Procedure

The task was identical to Experiment 7, except the slider direction was switched so that it now corresponded to the slider direction in Experiment 6. Therefore, to increase a target circle using the horizontal slider, a movement to the left was required. Correspondingly, a movement to the right on the horizontal slider would decrease a target circle's size. On the vertical slider, to increase the size of the target circle required an upward movement, whereas to decrease a downward movement was required. All aspect such as starting size, sensitivity and the dimensions of constructed annuli arrays from Experiment 7 were maintained (see Figure 1).

In total there were 3 different right side condition (Isolated, LA, and SA Condition), with 4 different starting sizes for each condition tested 10 times randomly for a total of 120 trials.

Experimental Design and Data Analysis

Identical data analyses were conducted on Experiment 8 as were employed in Experiment 7.

Results

A main effect for Condition, $F(2, 20) = 17.06$; $p<0.0001$, was evident with post-hoc analysis confirming that the control condition of 100.99 pixels (overestimated by 0.99 pixels) was not significantly different from the LA condition of 99.30 pixels (underestimated by 0.70 pixels), but was significantly different from the SA condition of 105.55 pixels (overestimated by 5.55 pixels). The post-hoc analysis further confirmed that the LA condition was significantly different from the SA condition (see Figure 2).

A main effect for Starting Size, $F(3, 30) = 3.35$; $p.<0.05$, was evident with post-hoc analysis confirming that significant difference lied between the smallest starting size (50%) and the largest starting size (150%) (see Figure 3). Post-hoc analysis further confirmed that the two increasing starting sizes were not significantly different from each other nor were the two decreasing starting sizes. On average, the mean of the two increasing starting sizes (101.62 pixels) were significantly different from the mean of the two decreasing starting sizes (102.27 pixels), demonstrating that the smaller starting sizes were more accurate than the larger starting sizes (Average error on "increase" trials = 1.62 pixels; average error on "decrease" trials = 2.27 pixels). Overall, the main tendency was to perceptually overestimate the left isolated target by 1.95 pixels.

Post Hoc Analysis to Comparator Value (100 pixels)

When the mean target ending size of the control condition of 100.99 pixels was compared against the comparator value of 100 pixels, it was confirmed that the overestimation in this experiment was not significantly different from 100. The mean target ending size when under the LA condition of 99.30 pixels was not significantly different from 100. However, the SA condition of 105.55 pixels was significantly different from 100 (see Table 1).

Trial Order Analysis

A main effect was only revealed for the Current Condition $F(2, 20)= 16.73$; $p.<0.0001$. Post-hoc analysis revealed that the control condition (100.91 pixels) was significantly different from the SA condition (105.54 pixels), but not from the LA condition (99.31 pixels). The SA condition was significantly different from both the LA and control conditions.

Between-Experiment Analysis (Experiment 8 versus Experiment 7)

A 3 (condition) by 4 (starting size) by 2 (direction) between- experiment analysis of variance (ANOVA) was conducted between Experiment 8 and Experiment 7. The purpose behind conducting a between-experiment analysis was to further investigate starting size as it applies to the physical increase and decrease of target circle's size. It was anticipated that if starting size (making bigger versus making smaller) was a significant mediator of these effects, there would be no main effect for group in the between- experiment ANOVA conducted on Experiment 8 and Experiment 7.

Results

A main effect for Condition, $F(2, 40) = 36.61$; $p.<0.00001$, was evident with post-hoc analysis confirming that the control condition (100.17 pixels) was not significantly different from the LA condition (98.56 pixels), but significantly different from the SA condition (104.57 pixels). Post-hoc analysis also confirmed that the LA condition was significantly different from the SA condition.

A main effect for Starting Size, $F(3, 60) = 7.11$; $p.<0.001$, was evident with post-hoc analysis confirming that the increasing starting size of 50% and 75% as well as the decreasing starting of 125% were significantly different from the largest starting size of 150%. As well a Condition by Starting Size interaction $F(6, 120) = 2.53$; $p.<0.05$, was evident with post-hoc analysis confirming that the differences not only arose between conditions across the 4 starting sizes but also there were significant differences within the LA and SA conditions across the 4 starting sizes. However, there were no significant differences between the 4 starting sizes within the control condition. A 2 mean post hoc comparison confirmed that when comparing the increasing starting sizes to the decreasing starting sizes the control condition was the only one in which the starting sizes were not significantly different. Comparing the starting sizes across conditions with a 3 mean post hoc, it was confirmed that both the increasing and decreasing starting sizes were significantly different.

Post Hoc Analysis (Experiment 8 versus Experiment 7)

The mean target ending sizes were not significantly different between Experiment 8 and Experiment 7. (Control Condition: Experiment 8 = 100.99 pixels, Experiment 7 = 99.35 pixels; LA condition: Experiment 8 = 99.30 pixels, Experiment 7 = 97.82 pixels; SA condition: Experiment 8 = 105.55 pixels, Experiment 7 = 103.58 pixels) (see Table 1).

Discussion

Overall, there was no between-experiment effect between Experiment 8 and Experiment 7, suggesting that the manipulation performed in Experiment 8 was not influential enough to change the misperceptions from Experiment 7. The starting size main effect was maintained which suggests that movement direction (moving towards versus moving away) relative to location of the illusion had no influence on the overall misperceptions, supporting the findings in both Experiment 6 and Experiment 7. Therefore, the fact that this starting size effect was maintained suggests that it is the increasing versus decreasing factors which seems to be contributing to the overall misperception more so then movement direction. These results are consistent with the results of Experiment 6 and Experiment 7.

Conclusion

The results of Experiment 8 suggest that neither the spatial location of the stimulus events nor movement direction (moving towards versus moving away) relative to location of the illusion are mediating factors, that effect the perceptual errors found from the Ebbinghaus illusions in Experiment 2.

Table 1.

Perceptual judgment errors in Experiment 8 relative to the 100 pixel comparator target and comparable conditions in Experiment 6 and and Experiment 7.

	Perceptual Judgment Errors in Experiment 8		
	Control Condition 100.99 pixels	Large Annuli Condition 99.30 pixels	Small Annuli Condition 105.56 pixels
Comparator Target 100 pixels	=	=	≠
Comparable Experiment 6 Condition	≠ (Control 97.09 pixels)	≠ (Large 96.47 pixels)	≠ (Small 101.32 pixels)
Comparable Experiment 7 Condition	= (Control 99.35 pixels)	= (Large 97.82 pixels)	= (Small 103.58 pixels)

Figure Captions: Experiment 8

Figure 1. Illustration of the experimental test conditions employed in Experiment 8 (one increasing and one decreasing starting size).

Figure 2. Mean ending size (pixels) and standard error as a function of condition against the100 pixels comparator target and the mean overshoot bias of 1.95 pixels.

Figure 3. Mean ending size (pixels) and standard error as a function of starting size against the100 pixels comparator target and the mean overshoot bias of 1.95 pixels.

Figure 1

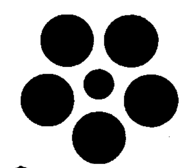
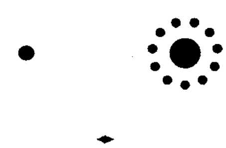
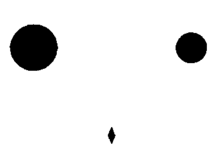
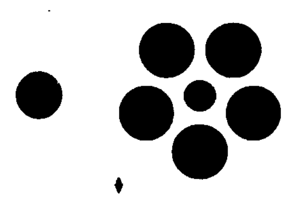
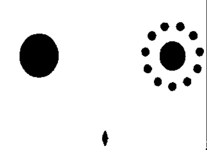
	Conditions in Experiment Eight		
	Left Central Comparator Target (100 pixels) / Manipulating Right Isolated Target		
Trials	***Left Central Target – Isolated***	***Left Central Target – Large Annuli***	***Left Central Target – Small Annuli***
Increase *Right Target Starting Size = 1.50 cm*	*Horizontal Slider Right to Decrease / Left to Increase*		
			
Decrease *Right Target Starting Size = 4.5 cm*	*Vertical Slider Down to Decrease/ Up to Increase*		
			

Figure 2

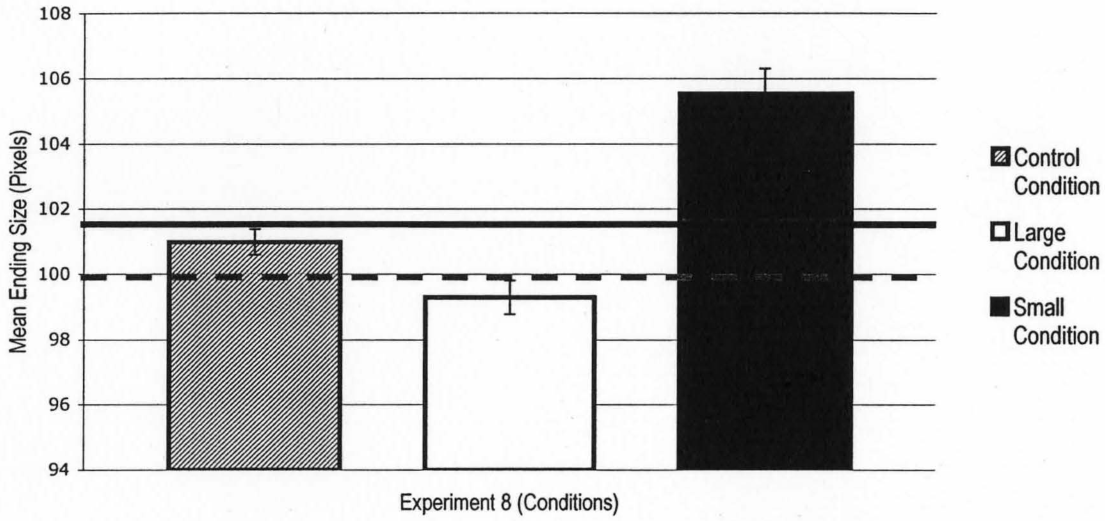
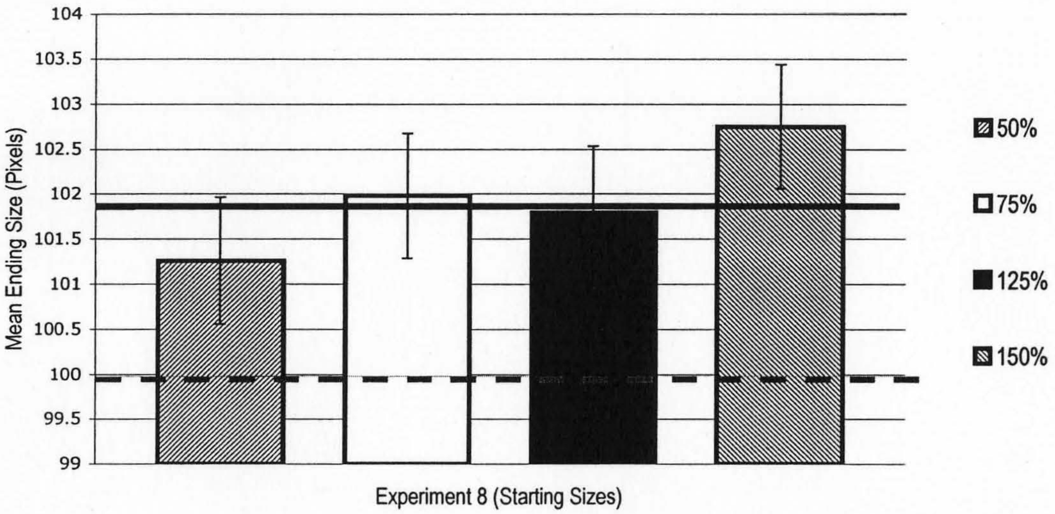

108
106
104
102
100
98
96
94
Mean Ending Size (Pixels)
Experiment 8 (Conditions)
Control Condition
Large Condition
Small Condition

Figure 3


104
103.5
103
102.5
102
101.5
101
100.5
100
99.5
99
Mean Ending Size (Pixels)
Experiment 8 (Starting Sizes)
50%
75%
125%
150%

GENERAL DISCUSSION

Visual illusions have been studied extensively as a tool, not only to investigate and gain insight into the underlying mechanism that control perception and action, but also as a way to assess the interaction between (or dissociation of) perception and action. This being said, however, there is still considerable controversy regarding the conditions under which visual illusions, and to what extent these illusions, affect the human perceptual and motor systems. Specifically, questions remain as to whether vision for perception and vision for action have separate or combined neurological processing streams. Numerous studies have shown that when under the influence of the Ebbinghaus Illusion, human perception of object size is at odds with the calculations generated by the human visuomotor system (Aglioti, DeSouza, & Goodale 1995; Goodale & Milner, 1992; Haffenden & Goodale 1998; and Plodowski & Jackson, 2001). These studies generally support Milner and Goodale's (1995) perception-action dissociation theory. However, numerous studies have also demonstrated results that are inconsistent with Milner and Goodale's perception-action dissociation theory (Dursteler & Wurtz 1998; Franz, Bulthoff, & Fahle 2003, Handlovsky et al., 2004; and Pavani et al., 1999). The most direct of these challenges arise from Glover and Dixon (2002) who propose a planning/control model of perception and action.

An extensive review of this past research suggests that studies can only infer perceptual effects of the Ebbinghaus Illusion. Many attempts to investigate these perceptual effects more directly (e.g., Aglioti, DeSouza, & Goodale, 1995; Bandarko & Senenov, 2004; Haffenden, Schiff, & Goodale, 2001; Pavani et al., 1999; and Plodowski & Jackson, 2001) have been faced with criticism for various reasons.

Specifically, it has been suggested that this contradictory evidence was the result of; 1) the choice of motor task in the experiment and 2) the different perceptual measures that have been used to reveal the illusionary effects (Franz, 2003; van Donkelaar, 1999). For example, many studies have used perceptual judgment tasks but due to potentially confounded methodological or design issues still offer conflicting interpretations as to the magnitude of the illusory influences observed. From the article review on perceptual measures employed thus far, no one design has been able to develop a clear and definitive tool to evaluate illusionary effects a thus create a more universal perceptual measure.

Two research questions were addressed directly in this thesis: 1) Is it possible to quantify (mathematically) the perceptual influence/perceived effect of the Ebbinghaus Illusion using a more accurate perceptual measure ?; and 2) Can this measure be utilized further to compare the perceptual and action influences of the Ebbinghaus Illusion, and thus the dissociation between perception and action? Results of Experiment 1A (control condition), 1B (LA condition), and 1C (SA condition), demonstrated overall misperceptions in the predicted directions. In other words, the control condition was accurate whereas the LA condition produced a significant undershoot bias and the SA condition produced a significant overshoot bias. Therefore, Experiment 1 demonstrated that the constructed illusionary conditions were effective in producing the typical Ebbinghaus illusionary effects.

As mentioned earlier, it has been long established that prior events can have a significant influence on subsequent movements. As we have suggested throughout this thesis, it is necessary to acknowledge this influence with respect to mediation and adaptation effects on perceptual error under illusionary conditions. Indeed, research in this area has typically and routinely employed experimental protocols in which participants are required to interact with many different illusory stimuli that are presented randomly and over a period of many trials. A potentially major problem with this approach is that it effectively ignores the possibility that an individual's perception of a given stimulus event remains both constant across time and remains independent of other object characteristics contained with the stimulus array. This assumption carries with it some dangers. Specifically, if some level of stimulus adaptation occurs across time, it can be argued that how an individual is influenced by an illusion at the end of many trials is fundamentally different from how they were influenced by it on trial one. In fact, there is reason to believe that illusionary effects will differ when they are presented in combination than when they are presented in isolation. Specifically, Adaptation Level Theory (Helson, 1947) suggests that if an individual is exposed to repeated and random presentations of multiple stimuli, an adaptation will develop wherein participants will generate an internal representation taking on all of the characteristics of the stimuli events presented in the stimuli set. They then use this representation as a visual reference to make appropriate comparisons. In essence, what ALT predicts in these circumstances is a hysteresis effect in which any given stimulus-response interaction will be progressively mediated by the environmental context and past exposures to repeated stimulus events.

Most all research investigating the Ebbinghaus Illusion in the past has operated under the assumption that these illusions are essentially free of such hysteresis effects. Thus, it is necessary to be able to investigate the magnitude of illusory effects when Ebbinghaus stimuli are presented in both isolated and combined stimulus environments. This was accomplished by utilizing the exact same stimuli as in Experiment 1, but presenting them in a combined random (unpredictable) stimuli set (Experiment 2). Results of these between-experiment comparisons suggest that participants are indeed experiencing some level of perceptual adaptation that is driven by the presence of multiple stimuli within the array. Of interest here, however, was the finding that this adaptation did not take the form predicted by ALT. Specifically, participants did not seem to be formulating a "pooled stimulus experience" to serve as an internal representation. Were this to be the case, it would be predicted that the respective undershoot and overshoot biases associated with the two illusory conditions would lessen. In other words, the robustness of the illusory effects would reduce such that any observed perceptual biases would approach that of the control condition. This did not happen. Rather, the multiple stimulus presentations in Experiment 2 resulted in a situation wherein the perceptual error of the control and SA conditions approximated that of the LA condition. The end result seems to be that, although some degree of stimulus adaptation is occurring, it is doing so in a way that suggests any internal representation approximates the most salient (i.e. LA) condition. It is also interesting to note that in Experiments 3,6,7,and 8, the control conditions were not significantly different from the LA condition. In all experiments, the control condition was significantly different from the SA condition, even when presented only with the SA (Experiment 4). It was also demonstrated that the SA condition remained susceptible to, and influenced by, the LA condition in all combined illusionary environments.

These experiments suggest that when participants are uncertain as to what condition will come next (combined environments), they seem to treat every condition like the LA condition thus demonstrating the dominating LA bias.

As well, several unanticipated effects were observed for variables that were originally intended to be control variables. Thus, Experiment 3 through Experiment 8 further investigated these adaptation effects and systematically eliminated possible confounds that arose within the methodologies of Experiment 2. No between group interactions were observed between Experiment 2 and Experiments 3 through Experiment 8, suggests that the issues addressed in these experiments are not influential contributors to any overall adaptation effects or misperceptions revealed in Experiment 2. Specifically, these results suggest that movement direction (towards/ away from illusion); the direction of the slider (horizontal / vertical); and side of space in which the illusions are presented were not significant mediators of the misperceptions revealed in Experiment 2.

The consistent starting size effect, however, was present in all Experiments. The results of Experiments 6, 7, and 8, suggest that it is the physical manipulation requirements of starting sizes (increasing/decreasing) that was the most influential variable. One possible explanation for this consistent starting size effect is the Range Effect (Poulton, 1974) as demonstrated in all experiments.

GENERAL CONCLUSION

Testing in a random (unpredictable) versus repeated (predictable) stimulus set is crucial to the overall perception of visual illusions. The experiments conducted in this thesis demonstrate that illusionary misperception will differ dramatically if presented in isolation rather then in a combined environment. Therefore, caution is to be stressed when combining illusions together in a random and repeated environment since there seems to be an adaptation effect in which the LA condition perceptually dominated.

Acknowledging that perceptions of identical stimuli may changes across the course of time due to prior exposures to different perceptual stimuli is a very important issue to consider especially when investigating the presence of the Ebbinghaus illusion in different motor tasks such as aiming and grasping. The fact that this thesis demonstrated that past exposures to different perceptual stimulus events have a significant influence on subsequent perceptual experiences, demonstrates that the visual system and the Ebbinghaus illusionary influences are susceptible to dynamic changes. Therefore, when studying this illusion in a motor centered task, adaptation level effects should be considered as a potential influence.

In summary, this thesis investigated the Ebbinghaus illusion and in doing so, employed an experimental tool that addresses many confounds and criticisms facing alternative perceptual quantification. It is believed that the perceptual measure used in this thesis could be used as a stepping stone toward a universally acceptable perceptual measure for aiming and grasping tasks and help resolve controversy between the vision for perception and vision for action dichotomy. The fact that the stimuli have each been perceptually quantified in both isolated and random environments makes for an easy comparison of the same stimuli under motor and action centered tasks.

It is believed that this thesis has many important contributions to extend into the research community, not the least of which is demonstrating how the perceptual biases of illusionary conditions dynamically change (i.e., adapt to multiple stimuli exposure) when faced with other illusionary stimuli in a random combined environment. It was also demonstrated that the magnitude of illusionary effects in isolated environments does not represent those magnitudes when they are combined in a multiple illusionary environment. It must be noted, however, that that this hysteretic change in adaptation was only seen when both illusionary conditions were present. Therefore, if visual illusions are to provide insight into the underlying mechanisms that control perception and action, it is important for researchers to understand these issues.

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