Examining the Role of Object Size in Judgments of Lateral Separation

by

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ABSTRACT

The goal of the present research was to examine the influence of object size on judgments of lateral separation using a one-shot change detection paradigm. Prior research on judgments of separation (e.g., Levin & Haber, 1993) argued that visual angle is the predominant determiner of judgments of depth and separation (i.e., exocentric distance). Gogel and Da Silva (1987a) proposed a two-process theory to explain depth judgments. This theory states that both perceptual (e.g., visual angle) and cognitive factors (e.g., familiar size) influence people's ability to judge the distance to an object. The present research consists of four experiments which extended the investigation of size cues to judgments of lateral separation and evaluated their consistency with Gogel's theory of off-sized perceptions.

Experiments 1 and 3 used a forced-choice response, finding a significant influence of object size on distance judgments. Participants accurately detected changes in linear separation. Concurrent changes in object size, however, significantly reduced the accuracy of distance judgments. Moreover, pattern mask duration was varied and two interference conditions were included in Experiment 3. Longer mask durations appeared to exacerbate a trend to underestimate distances and the effectiveness of size cues was somewhat reduced by the interference task. These results are compatible with the view that size cues typically influence a secondary, cognitive stage of processing whose effect is diminished due to competition for resources with the interference task.

Experiments 2 and 4 replicated the results of Experiments 1 and 3 using a distance reproduction task. In Experiment 2, participants dragged the mouse to reproduce a distance given in a source image from memory. Similar to the forced-choice results of Experiments 1 and 3, changing object size was reflected in a linear change in distance reproductions. In Experiment 4, participants both estimated line lengths using a given square as a metric (line estimates) and produced lines of *n* square-lengths (line production). The results of Experiment 4 provided converging evidence that object size influences judgments of lateral separation regardless of response type. In summary, the present research identifies that object size is a significant determiner of judgments of lateral separation consistent with the predictions of Gogel's Theory of Off-sized Perceptions.

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Finally, I would like to thank my parents George and Paula Thomson, who taught me to work to the best of my ability and follow through, even when a problem seems insurmountable.

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INTRODUCTION

The ability to recognize objects and judge distances is essential for navigating through the environment. During object recognition, an observer will automatically determine the *angular size* of an object as it falls on her retinas and, in many cases, then perceive the object as having an expected size or range of acceptable sizes (i.e., its *familiar size*; Haber & Levin, 2001). For instance, once a student recognizes that an object on a table is a beer bottle, the student has access to the familiar size of the bottle (approximately 20 cm tall). This metrical size judgment is also referred to as the *linear size* of an object. In addition to size perception, there are two types of distance perceptions: egocentric and exocentric. *Egocentric* distance perception is the perception of an object in depth, that is, a judgment made of the distance between one's self (as the observer) and an object. Using a football analogy, egocentric distance perception is the kind of perception that the quarterback uses when he decides how far to throw the ball downfield to reach his receiver. *Exocentric* distance perception is the perception of inter-object distance, that is, a judgment made of the distance between two objects irrespective of observer position. Returning to the football analogy, exocentric distance perception arises, for instance, when the quarterback estimates the distance between his wide receiver and the opposing team's defensive back.

The size-distance invariance hypothesis (SDIH) was an early attempt to capture the relationship between size and distance perception (Filpatrick & Ittelson, 1953). It states that observers expect that an object at a relatively farther distance will project a smaller retinal image size than the same object at a relatively closer distance (Carlson & Tassone, 1962). While the majority of size and distance judgments are consistent with this hypothesis, task instructions and certain visual illusions have generated apparently contradictory evidence (Baird, Wagner & Fuld, 1990; Epstein, 1963). For instance, when observers are asked to judge how far away an object feels to them (its *apparent distance*), their answers tend to ignore familiar size cues and correspond more to the object's angular size. If instead observers are asked to judge how far away an object would be if measured with a meter stick (its *objective distance*), then their answers tend to be influenced by familiar size cues (Carlson & Tassone, 1971). There is currently no process specified in the size-distance invariance hypothesis that captures the differential effect of task instruction on size and distance judgments.

In addition, visual illusions have also provided evidence not captured by the SDIH. For instance, the moon at its zenith appears both smaller and farther away than along the horizon, a finding that is inconsistent with the size-distance invariance hypothesis (Kaufman & Rock, 1962). The size-distance invariance hypothesis instead predicts that when the moon appears smaller at its zenith, it should appear closer than when along the horizon, not farther away. This incongruence is called the size-distance paradox (Kaufman & Kaufman, 2000).

To account for this contradictory evidence, the size-distance invariance hypothesis was modified to represent a relation between apparent size, apparent distance, and (arguably) apparent visual angle (McCready, 1985). This single-process model of size and distance perception presupposed that size judgments could not dissociate linear size determined primarily by angular size from linear size influenced by familiar size and other "cognitive" cues. In other words, *perceived* linear size and *cognitive* size judgments could not be disentangled and were thus part of an encapsulated process. However, Gogel

(1976, 1981; Gogel, Loomis, Newman, & Sharkey, 1985) developed an indirect head-motion tracking technique to measure perceived egocentric distance and found only a negligible effect of familiar size on perceived distance. This evidence suggested that the cognitive size predominantly influenced only direct reports of distance (e.g., verbal judgments) and not "raw" representations of perceived distance (Gogel, 1976, 1981; Mershon & Gogel, 1975; Predebon, 1992; Tyer, Allen, & Pasnak, 1983). The head-motion technique experiment results led to the conclusion that perceived size (determined by angular size) and distance could be dissociated from cognitive judgments of size and distance.

Consequently, Gogel and Da Silva (1987a) postulated a two-process theory, called the *theory of off-sized perceptions*. The primary process is *perceptual* and is determined by the size-distance invariance hypothesis. The secondary process is *cognitive* and is influenced by familiar size cues. Attention, the availability of visual cues, and experimenter instructions determine the extent to which the secondary process influences distance judgments. For instance, when an object is perceived as off-sized (i.e., when its perceived size is different than its expected or familiar size), the cognitive secondary process are more heavily weighed. The evidence used to support the theory of off-sized perception has exclusively been based on judgments of depth. Thus, it has been shown to be valid for egocentric judgments only.

While the theory is claimed to be a generalized model for size and distance perception, it has also been argued that egocentric and exocentric judgments subsume separate processes (Gogel, 1965). Therefore, it is not clear that the theory of off-sized perceptions can be applied in the same manner to exocentric distance judgments or to judgments of lateral separation, which are a depth-controlled subset of exocentric distances. There is evidence, however, that egocentric distance judgments and judgments of lateral separation do use similar processes. Sterken, Postma, De Haan, and Dingemans (1999), for instance, used a change detection task to determine whether egocentric distance and lateral separation information are independently stored in visual memory. They showed that co-occurring lateral displacement during an egocentric judgment reduced the accuracy of egocentric judgments below-chance levels. Similarly, co-occurring egocentric displacement during judgments of lateral separation reduced the accuracy of judgments of lateral separation to at-chance levels. This interference between egocentric and lateral separation information indicates that representations of egocentric distance and lateral separation are correlated.

The goal of this thesis will be to extend prior research by investigating the familiar size cue in relation to judgments of lateral separation. In particular, judgments of lateral separation will be shown to be affected by familiar size cues. Furthermore, a change detection methodology will be introduced as a novel technique for studying the effectiveness of familiar size cues. An advantage of the change detection methodology is that it allows response times to be recorded, which will provide additional evidence for a multi-process model. In the remainder of the introduction, I will present prior research on size and distance perception using evidence from the size-distance invariance hypothesis and Gogel's theory of off-sized perceptions. I will then argue for the extension of the theory of off-sized perceptions to judgments of lateral separation. Finally, I will present my motivation for the adoption of a change detection methodology and explain how response times can be used to distinguish between several possible processes involved in distance perception.

Terminological Conventions

Throughout this document, a consistent naming convention will be used when describing the different features of size and distance perception. To make the relation between this convention and the terms used interchangeably throughout the literature as clear as possible, I will define the major terms and their synonymous referents.

When referring to *visual angle*, the current document will refer to the extent of the object or distance as it is projected on one's eyes. This is also referred to as *retinal* or *angular size/distance*. *Perceived size* or *perceived distance,* as defined by Gogel and Da Silva (1987a), refers to perceived linear size or distance determined predominantly from angular size in accordance with the size-distance invariance hypothesis. *Apparent size* or *apparent distance* refers to any judgment of size or distance which has been affected by cognitive inferences, attentional processes, or memory effects. Apparent size/distance is thus considered *subjective* or *phenomenal*. It does not imply, however, that all cognitive processes are consciously accessible. Apparent size or distance is most closely related to what Gogel and Da Silva refer to as *cognitive* size or distance.

Finally, *familiar size* refers to any prior or expected knowledge of size. Normally, familiar size cues are based on prior experience. Gogel (1965, 1998), however, argued that during the sequential presentation of stimuli, the first presentation serves as a baseline size by which subsequent presentations are judged. Thus, in such a situation, the initial presentation (i.e., the source image) is a template or anchor by which subsequent presentations are evaluated (i.e., the target image). This definition of familiar size, however, does not involve prior experience in the traditional sense. In the introduction, familiar size will be used in the traditional sense of a prior knowledge of size. In the Experiments, familiar size will refer to Gogel's sequential-template definition.

The Size-Distance Invariance Hypothesis

The size-distance invariance hypothesis (SDIH) resulted from early attempts to describe the relationship between size, distance, and visual angle perception (Filpatrick & Ittelson, 1953). It states that observers expect that an object at a relatively farther distance will project a smaller retinal image than the same object at a relatively closer distance (Carlson & Tassone, 1962). The original equation for the SDIH is presented in Equation 1:

$$\frac{S}{D} = \tan(\theta) \qquad (1)$$

where S is perceived size, D is perceived distance, and θ is visual angle. The SDIH has three corollaries. First, when visual angle is constant, perceived size and distance should vary proportionally. When two objects are equal in visual angle, the one perceived as more distant should be larger in perceived size (Carlson & Tassone, 1971; Emmert, 1881). Second, when perceived distance is constant, perceived size should vary proportionally with visual angle. For example, for two objects at identical apparent distances, the object subtending a greater visual angle should be perceived larger in size than another object with a smaller visual angle. Finally, when perceived size is constant, perceived distance varies inversely with visual angle. Thus, an object subtending a larger visual angle will be perceived closer than a similar object subtending a smaller visual angle.

According to the SDIH, if two similarly-sized objects subtend the same visual angle and are perceived to be the same size, then they must be perceived at the same depth. Carlson and Tassone (1971) found, however, that when observers made relative distance judgments of an object having a familiar size (a cardboard cutout of a woman), it was seen as relatively more distant and shorter than a similarly-sized cardboard rectangle. It appeared that the familiar size of the cardboard-cutout woman acted as a cue to alter perceived size, which then altered perceived distance in accordance with the SDIH.

In a more rigorous setting, Park and Michaelson (1974) had participants make quantitative distance judgments in a visual alley to control for depth cues. Participants monocularly viewed an electroluminescent disc 6.35 cm in diameter and 1.83 m away from the viewing port.[1] They were shown a transparency of a similarly-sized familiar object (golf ball or baseball) as a size cue or were given a *known size* for the object (6.35 cm or 12.70 cm). Familiar size cues calibrated distance judgments such that on trials where the baseball was presented, distances were judged farther (M = 4.48 m; expected 3.66 m) than on trials where the golf ball was presented (M = 1.98 m; expected 1.83 m). Consistent with the SDIH, familiar size affected perceived size, which then affected perceived distance. When a known size was verbally provided to participants, no familiar size effects were present (M = 2.44 m, 2.04 m for 6.35 cm or 12.70 cm told, respectively). These results further suggested that familiar objects must be seen to yield familiar size effects.

Tyer, Allen, and Pasnak (1983) replicated Park and Michaelson's (1974) methodology and distance judgment results, finding that familiar objects calibrated

[1] All sizes and distances in this thesis will be reported in the metric system. When the studies that are reviewed presented Imperial/US measurements, the values were converted to metric units.

distance judgments. A difference between the studies was that known size did significantly calibrate distance judgments. The effect, however, was minimal and only a fraction of that predicted by the SDIH. Tyer et al. also extended Park and Michaelson's methodology by having participants make size judgments after being given verbal distance information. Providing distance information calibrated size judgments in the direction predicted by the SDIH. Nonetheless, size was once more underestimated.

To summarize, providing familiar size information calibrates distance judgments and providing verbal distance information calibrates size judgments, both in accordance with the SDIH. In addition, comparing a stimulus to a similarly-sized familiar object better calibrated distance judgments than providing a known size. However, when size or distance information is verbally given (as opposed to familiar size), the calibration effect is often significant, although only a fraction of the value predicted by the SDIH.

Limitations and Modifications of the Classical SDIH

The original SDIH has been shown to be roughly accurate for most perceptions (Gogel, 1976; Park & Michaelson, 1974; Carlson & Tassone, 1971; Epstein, 1963; Carlson, 1962) and visualizations (Hubbard, Kall, & Baird, 1989). Nevertheless, it has been shown to be strongly influenced by task instructions (Gogel & Da Silva, 1987b; Higashyama, 1984; Epstein, 1963; Carlson, 1962) and certain visual illusions (Wagner, Baird, & Fuld, 1990; McCready, 1985; Kaufman & Rock, 1962).

The Role of Task Instructions on Size and Distance Judgments

Carlson (1962; Carlson & Tassone, 1967) conducted a study to investigate the role of task instructions on size and distance judgments to better account for inconsistencies in the original SDIH. Carlson theorized that task instructions differentially weight which visual cues are to be used to determine perceived size and distance. Carlson had participants compare the size of a standard shape at 12.20 m to a similar variably-sized shape placed at 3.05 m in a parallel alley. Each pair of objects was judged under four task instruction variants. Apparent (or phenomenal) instructions asked participants to judge whether two objects or distances appeared, seemed to be, or "felt" equal. Objective instructions asked participants to judge whether two objects or distances *were* equal, such that if one measured the distance with a ruler, the same distance would be obtained each time. Perspective instructions asked participants to judge whether two objects or distances in depth were similar such that one would judge them to be the same if they were seen down a railroad track (i.e., under perspective). Finally, projective instructions asked participants to judge whether two objects at different depths would subtend the same visual angle.

The results showed that apparent instruction produced veridical size judgments, both objective and perspective judgments produced size overestimation, and projective instruction produced size underestimation. Surprisingly, objective instructions did not produce the most accurate judgments. Carlson (1960) argued that, in part, because objective and perspective instructions similarly influenced participants, objective instructions lead participants to adopt a perspective attitude when making size and distance judgments. From Carlson's results, it is evident that task instructions differentially weight visual cues such that apparent instructions tend to better calibrate size judgments relative to objective or projective instructions.

Epstein (1963) extended Carlson's (1960) methodology by utilizing the same four task instructions in a between-subjects design to control for any effect of prior instruction upon later judgments. Epstein varied the range of distances at which the standards were placed and also examined distance judgments. The stimuli included two different-sized triangle cutouts (7.6 cm and 15.9 cm) positioned in a visual alley. The standards were placed at a range of distances (from 3.05 m to 36.60 m) across trials, while the variably-sized triangle was always placed at a distance of 1.52 m, but at a 20° angle. The variable triangle's size could be modified by the participants until they felt it matched the size of the standard. Epstein's size judgment results were similar to Carlson's. Apparent instruction produced veridical size judgments, objective and perspective instructions produced size overestimation, and projective instructions produced size underestimation. Additionally, changing the distance of the standard did not alter size judgments. This result indicated that task instructions were not limited to or dependent on any particular distance range between 3 and 36 m.

This finding was further supported when Predebon (1990) replicated and extended Carlson and Tassone's (1971) study contrasting relative size and distance judgments of either a familiar-sized cardboard cutout of a woman or a similarly-sized rectangular cutout. Participants were asked to make both apparent and objective size and distance judgments. Under apparent instructions, the woman was seen as relatively smaller and more distant than the rectangle. This result replicated that of Carlson and Tassone, but not Epstein (1963). It is possible that because the observers made a relative size judgment, they were more likely to report "feeling" that the woman was relatively smaller. Predebon argued, however, that if this judgment had been quantified using a metric, the size difference would not have been significant. Conversely, under objective instructions, the woman appeared of similar size or relatively larger (at distance greater than 120 m) than the rectangle. The relative overestimation of size due to objective instructions was consistent with Epstein (1963). Overall, these results support the differential effect of task instructions on size judgments.

More importantly, with regards to the present thesis, Epstein (1963) examined not only object size judgments but also distance judgments. In the distance judgment condition, both the variable and standard triangles were the same size throughout the trials. Distance judgments were made by using a modified slide-ruler acting as a scale mockup of the visual alley. The fixed-location "scale-variable" triangle was at a fixed location on the ruler (corresponding to a scale of the 1.52 m location in the visual alley), while the "scale-standard" triangle's position could be varied. The distance ratio of the two triangles was then converted to distance judgments. Contrary to the size judgment results, there was no effect of task instruction on distance judgments. This asymmetry between task instructions' effect on size and distance judgments implies that size and distance perception might not be captured in a single process model like the SDIH.

Since Epstein (1963), most studies have contrasted apparent and objective instructions. Although there were some early concerns that participants may have more difficulty understanding apparent instructions than objective ones (Carlson & Tassone, 1967), subsequent studies (Mershon & Gogel, 1975; Gogel, 1976; Predebon, 1990, 1992) confirmed that participants could accurately understand both types of instructions. They have also confirmed that apparent instructions tend to provide more veridical size judgments (with a tendency to underestimate farther distances) and minimize familiar size effects on egocentric distance judgments. In contrast, objective instructions tend to elicit more familiar size effects (Gogel 1976; Gogel & Da Silva, 1987a; Higashiyama, 1984; Mershon & Gogel, 1975; Tyer et al., 1983). Moreover, participants continued to exhibit the same degree of overestimation for objective and perspective instruction and they were found to be unable to understand projective instructions. Hence, perspective and projective instructions were dropped from later research.

In summary, apparent and objective task instructions differentially influence size (and to a lesser extent, distance) judgments. Most importantly (and surprisingly), apparent instructions tend to minimize familiar size effects on distance judgments, while objective instructions tend to elicit more familiar size effects. It is possible that for objective task instructions, observers are trying to maximize available cues, which include familiar size cues. By comparison, for apparent task instruction, when observers are asked to judge how a size or distance "feels to them", they utilize a *first-glance* heuristic which limits inferred cues and focuses perceptions from the SDIH (e.g., basing judgments predominantly on angular size). To further examine the influence of available visual cues on size and distance judgments, I will now review research about two key visual illusions and present possible modifications to the SDIH to best account for these illusions.

The Role of Visual Illusions and the Size-Distance Paradox

In the previous section, evidence showing violations of the classical SDIH was presented. There are two major illusions which also violate the classical SDIH: the *moon illusion* and the *Ebbinghaus illusion.* To resolve the apparent paradoxical movement of the moon, theories have been put forth to determine whether a misperception of distance or a misperception of visual angle may be the cause of these illusions. Evidence from studies of the Muller-Lyer illusions have further shown that a misperception of visual angle may be an oversimplification of the actual processes involved in these phenomena.

The Moon Illusion

The moon illusion occurs when an observers infers that the moon at its zenith appears smaller and farther away than when it is at the horizon (see Figure 1). However, according to the classical SDIH, when two objects subtend the same visual angle, the object perceived as larger should appear farther away. In fact, the inferred larger horizon moon appears closer. Even when an artificially larger moon was projected onto a simulated zenith sky and artificially smaller moon projected onto a simulated horizon sky, participants still judged the zenith moon smaller and farther than the horizon moon (Kaufman & Rock, 1962). To account for this *size-distance paradox* (Epstein et al., 1961), several modifications to the classical SDIH have been proposed.

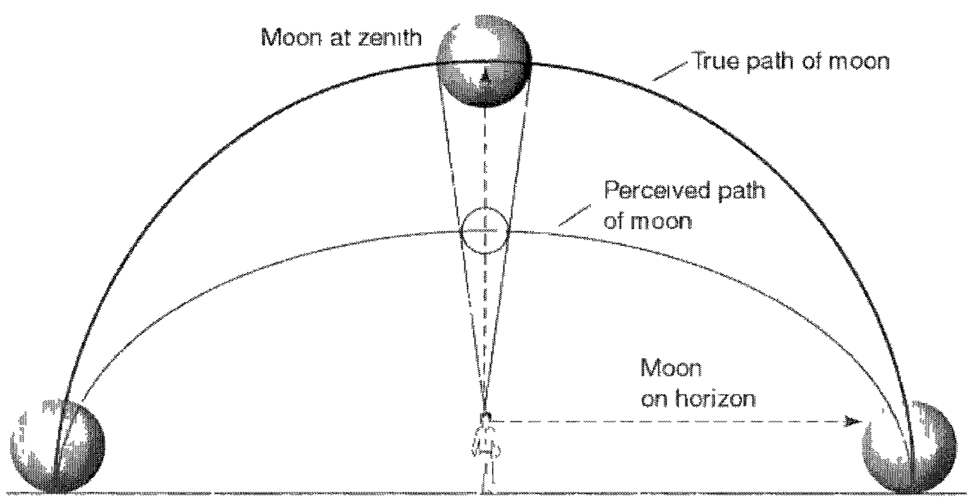

Figure 1. The moon illusion. No matter the moon's location in the sky, the distance between an observer and the actual path of the moon remains relatively constant. Nonetheless, observers perceive the moon to become smaller as it approaches its zenith.

Kaufman and Rock (1962; Kaufman & Kaufman, 2000) have articulated an *apparent-distance theory* to account for the size-distance paradox. Initially, objects along the horizon like trees and buildings provide pictorial cues (e.g., occlusion & perspective) which affect the observer's perception of both the size and distance of the horizon moon. Knowing that the moon does not actually change size as it travels across the sky, relative size cues to distance then lead observers to judge the apparently larger horizon moon closer than the apparently smaller zenith moon. Similarly, Gogel (1969) argued that the zenith moon takes on a relatively closer default distance than the horizon moon due to a lack of comparison objects and the specific distance tendency. This closer default distance scales the perceived size of the zenith moon, resulting in the zenith moon appearing both closer and smaller than the horizon moon. In opposition, Roscoe (1989) and McCready (1985) have argued that a misperception of the perceived angular size of the zenith moon causes the moon illusion. Kaufman and Kaufman (2000), however, determined that the apparent angular size of the moon at its zenith could not account for changes in its apparent perceived distance.

Due to the intrusion of familiar size and distance cues that necessarily involve memory processes, the classical SDIH (Equation 1) was revised to take into account cognitive aspects of size and distance judgments:

$$\frac{S'}{D'} = \tan(\theta) \qquad (2)$$

where S' is apparent size, D' is apparent distance, and θ is visual angle. Apparent size and distance were considered subjective measures which include the effects of prior knowledge (e.g., the familiar size of other reference objects such as trees). These variables (S', D') are to be distinguished from perceived size and distance (S, D). The latter are considered to be objective measures primarily derived from the angular size of objects and egocentric distance cues such as convergence and accommodation. Baird, Wagner, and Fuld (1990) provided evidence for apparent size effects influencing size judgments in the moon illusion. They showed that if one examines the horizon moon through a tube to eliminate the objects along the horizon, the moon illusion disappears. This disappearance of the moon illusion implies that our perception of the moon is (or can be) accurate, but that nearby objects influence our judgments of size and distance. The apparent-distance theory can account for the moon illusion in a manner that is consistent with the SDIH (as given in Equation 2). It cannot, however, account for the presumable lack of relative depth change in the Ebbinghaus illusion.

The Ebbinghaus Illusion

The Ebbinghaus illusion (shown in Figure 2) presents two identically-sized circles that are placed near each other. One is surrounded by larger circles, while the other is surrounded by smaller circles. The illusion is that the circle surrounded by the larger circles appears smaller than the circle surrounded by smaller circles by approximately 20% (McCready, 1985). To examine whether the modified SDIH (from Equation 2) could explain the Ebbinghaus illusion, it was adapted for the comparison of multiple objects in the following equation:

$$\frac{(S_2'/D_2')}{(S_1'/D_1')} = \tan\left(\frac{\theta_2}{\theta_1}\right) \qquad (3)$$

From Equation 3, it is apparent that, for a constant visual angle of the central circles (θ_1 and θ_2), any difference in the ratio of the apparent size of the circles must be reflected by a similar change in inferred depth to preserve the SDIH. Thus, assuming a 20% change in inferred size, the difference in the inferred size of the central circles ($S'_2 / S'_1 = 1.2$) should cause a change in the inferred depth between the circles ($D'_2 / D'_1 = 1.2$). Over

90% of people, however, do not report that the central circles appear displaced in depth compared with each other or the nearby circles.

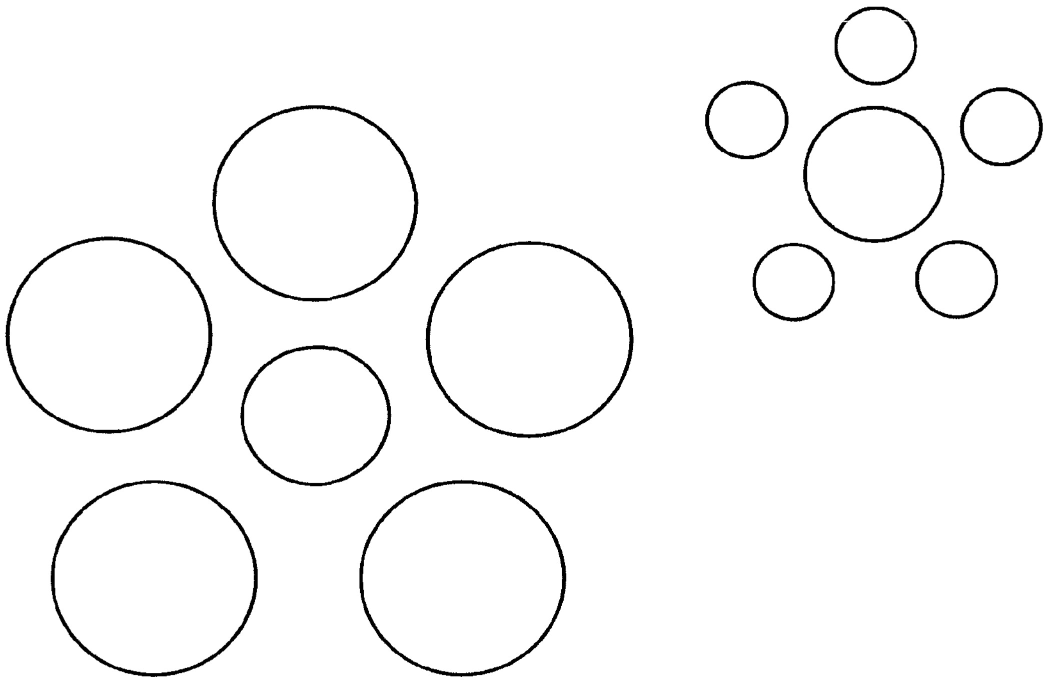

Figure 2. The Ebbinghaus illusion. The Ebbinghaus illusion is created when two target circles of identical sizes, one flanked by smaller circles and the other flanked by larger circles are presented side by side. This stimulus arrangement generates the illusion that the target circles are of different sizes.

McCready (1985, 1986) argued that, because apparent (or perceived) distance is unaffected by the Ebbinghaus illusion, the illusion must be due a misperception in visual angle and not a misperception in size. Moreover, because the central circles subtend the same angle on viewers' retinas, this misperception in visual angle is better defined as an apparent visual angle. Thus, he argued that Equation 3 should be revised to include inferred visual angle:

$$\frac{(S_2'/D_2')}{(S_1'/D_1')} = \tan\left(\frac{\theta_2'}{\theta_1'}\right) \quad (4)$$

In Equation 4, θ' is the apparent visual angle and reflects whatever underlying mental processes cause a misperception of visual angle. Assuming that the primary source of the Ebbinghaus illusion is a misperception of visual angle ($\theta'_2 / \theta'_1 = 1.2$) and assuming that perceived distance remains equal, then the misperception of visual angle should be reflected as a change in perceived size ($S'_2 / S'_1 = 1.2$) consistent with Equation 4. Consistent with this view, fMRI evidence has identified that an object subjectively perceived as larger occupies a larger retinotopic area in the visual cortex (more precisely, V1) than an object subjectively perceived smaller, even if both are in fact the same angular size (Murray, Boyaci, & Kersten, 2006). Minimally, this implies that information about angular size and distance are integrated early in perception.

Baird et al. (1990) argued that the basis for this apparent visual angle is in part due to the relative size of nearby objects, or in other words, the ratio of the visual angle of the critical object compared to the visual angle of nearby objects. To illustrate this insight using the moon illusion as an example, the following equation is obtained:

$$S' = D' * tan\left(\frac{\theta_a'}{\theta_r'}\right) \quad (5)$$

where θ_a' is the visual angle of a critical object (e.g., the moon or the centre circle in the Ebbinghaus illusion) and θ_r' is the visual angle of nearby objects (e.g., trees and buildings in the moon illusion or the nearby circles in the Ebbinghaus illusion). Apparent size is thus a function of distance and the ratio of the apparent visual angle of the centre circles to the surrounding circles. Gogel (1965) refers to the influence of nearby (or adjacent) objects on size judgments as the Gestalt-like a*djacency principle*.

The Muller-Lyer Illusion

In the traditional Muller-Lyer illusion, two lines of equal sides are flanked by arrowheads either pointing in or pointing out (see Figure 3). The line where the arrowheads point in is misperceived longer than the line where the arrowheads point out. Further examining the results of the Muller-Lyer illusion, however, questions whether visual angle is really "misperceived". Yarbus (1967; replicated by de Grave, Smeets, & Brenner, 2006), conducted an eye-tracking study of the Muller-Lyer illusion, and found that observers may saccade up to 30% farther (M = 9% in de Grave et al., 2006) for the apparently longer line than the apparently shorter line even though both lines are the same length and subtend the same visual angle. A saccade past the end of the line into the area by the concave arrowhead (e.g., the upper-left stimulus in Figure 3), however, is not a misperception of visual angle but a misperception of linear size based on some feature of the arrowheads (or end stimulus such as squares). Even if saccades are controlled for (i.e., controlling for visual angle), the Muller-Lyer illusion still occurs (Bolles, 1969). It thus appears that a misperception of visual angle (or the use of apparent visual angle) is insufficient to account for the evidence from the moon, Ebbinghaus, and Muller-Lyer illusions.

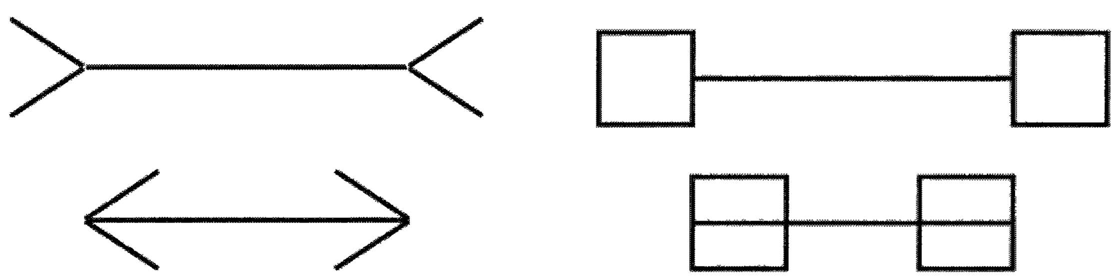

Figure 3. Two examples of the Muller-Lyer illusion. In the traditional Muller-Lyer image (on the left), the orientation of the arrowheads affects the perception of the length of the lines. In the variant on the right, the arrowheads are replaced by squares. The lower line is perceived shorter even though it is the same length as the upper line.

In an alternate explanation of the Muller-Lyer illusion, Gregory (1963) proposed that the illusory effects are due to perspective-based size constancy. In short, Gregory argued that when the arrowheads are concave (lower-left), they trigger a perspective-based size constancy with a concave 3D corner (see Figure 4). Conversely, when the arrowheads are convex (upper-left), they trigger a perspective-based size constancy with a convex 3D corner. For Gregory, perspective-based size constancy was driven by a two-process model. The primary constancy scaling process was set by perspective-based cues, and considered perceptual in that it was mediated by neural mechanisms early in the visual system. The secondary constancy scaling process was determined by apparent distance, based in part by previous knowledge and memory influences. This secondary process was similar to Kaufman and Kaufman's (2000) and Gogel's (1969) apparent distance theory to explain the moon illusion.

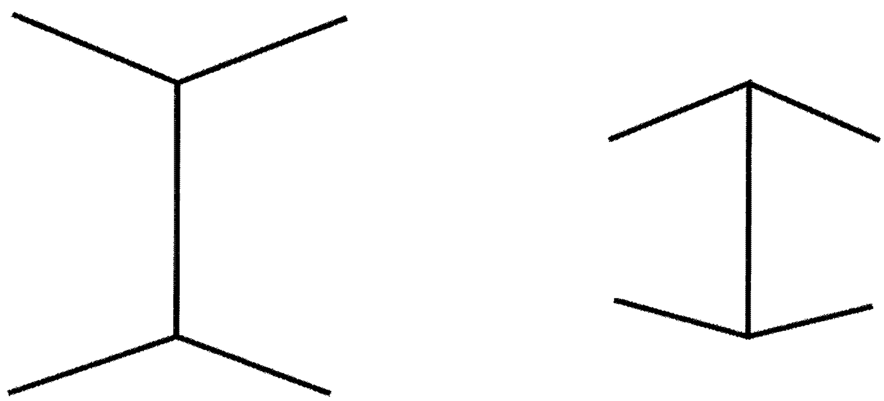

Figure 4. An example of a convex (left) and concave (right) simulated 3D corner. Due to perspective size constancy, it is theorized that the left image is longer because the line is apparently farther in depth in the convex corner than the concave corner.

More recently, Howe and Purves (2005) examined a large database for images of natural scenes and found no regularities in these scenes consistent with Gregory's (1963) concave-convex distinction. Furthermore, the illusion persists even when no concave-convex angles are visible (cf., the right-hand image in Figure 3). In further support of the thesis that the Muller-Lyer illusion arises from learned tendencies, Ahluwalia (1978) determined that people living in "uncarpentered" regions of Zambia exhibit less susceptibility to the Muller-Lyer illusion than those living in "carpentered" regions. An implication of the "learned" nature of the Muller-Lyer illusion, and the fact that some interpretations of the illusion rely on neural and early-perceptual systems, is that even early “perceptual” processing is prone to learning through prior knowledge. However, these learned heuristics, through repeated exposure, have developed automaticity and an apparently “primary” status independent of more recent and fluid knowledge cues such as apparent distance (Logan, 1988).

Visual Illusions: Dissociating Perception and Prior Knowledge

To summarize the role of visual illusion on the evolution of the SDIH, Kaufman and Rock (1962) initially argued that the size-distance paradox is due to pictorial distance cues affecting observers’ perception of distance. However, this apparent-distance theory cannot account for the apparent lack of depth in the Ebbinghaus illusion. McCready (1985) argued that the size-distance paradox is not due to a misperception of apparent size and apparent distance, but a misperception of apparent visual angle. Overall, the trend in the literature on the moon and Ebbinghaus illusions is to substitute perceived size, distance, and visual angle from the classical SDIH with apparent size, distance, and visual angle.

Substituting apparent size, distance, and visual angle (Equations 2 - 4) for perceived values (Equation 1) does raise some difficulties, however. Returning to the evidence from task instructions, it appeared that observers made an initial perception, and then, depending on task instructions, differentially utilized visual cues (such as familiar size) to make size or distance judgments. Evidence from the size-distance paradox is consistent with the theory that – at least in some situations – initial veridical "perceptions" occur and that separate "cognitive" processes then act upon these raw perceptions. For instance, when viewing the horizon moon, it appears both larger and farther away than the zenith moon due in part to inferred depth cues. Yet, when looking at the horizon moon through a tube (eliminating relative depth cues along the horizon), the illusion disappears. Nonetheless, this evidence is equally consistent with a single-process model (cf. Equation 4) and therefore cannot be used as direct evidence for a dual-process account.

Another possibility, brought forth by Gregory (1963), was to dissociate a primary neural early-perceptual process from a prior-knowledge based secondary process. While the particular perspective size constancy mechanism was insufficient to explain the Muller-Lyer illusion, the notion of a dual-process mechanism does explain the presumed effect of task instructions on size and distance judgments. Similarly, Gogel (1976, 1981; Gogel & Da Silva, 1987b) has proposed that size and distance perception may best be captured using a dual-process model that includes both perceptual and cognitive processes. For instance, some cues (such as those underlying perspective) seem perceptual (i.e., part of the early visual system) while others seem cognitive (e.g., those relying on prior knowledge and attentional components, such as familiar size and task instructions). Using a dual-process model, it may be possible to better explain the relative impact of cues at different levels of processing (e.g., perspective should always happen regardless of task instructions because it is an automatic heuristic of the visual system). The following section will examine in-depth the role of familiar size cues on distance perception and detail the evidence used to support Gogel's dual-process theory of off-sized perceptions.

The Role of Size and Distance Cues on Depth Perception

Research on both the moon and Ebbinghaus illusions has examined the role of relative size cues on size on distance perception, but not all researchers accept the adoption of a single-process SDIH based on apparent size, distance, and visual angle. Parallel research has posited a dual-process explanation for size and distance judgments by investigating the role that size cues exhibit on distance perception. Early research on size cues to distance suggested that familiar size calibrates perceived size, which then alters perceived distance (assuming the perception of a constant visual angle). Initially, this distance calibration was attributed to apparent size and the distance judgment to apparent distance, similar to the SDIH (cf. Equation 4). However, subsequent research (Gogel, 1976, 1981; Gogel & Da Silva, 1987b) has suggested that size, distance, and visual angle perception are very accurate, with variations in size and distance responses due to separate "cognitive" processes. Before proceeding to a specific examination of the research on familiar size cues, a general explanation of how another class of cues (here called distance cues) can affect distance judgments will be undertaken.

Distance Cues

To make accurate quantitative (i.e., absolute) distance judgments, there are only three sources of direct information available: the extra-ocular processes of accommodation and convergence, and the familiar size cue (Gogel, 1962; Foley, 1969;

Gogel & Tietz, 1979, 1980). Accommodation is the process by which extra-ocular muscles control the focal distance of the eyes. Convergence is the process by which extra-ocular muscles control the inward tilt of the eyes to maintain binocular fixation on an image. Binocular disparity is the difference in convergence angles that an object projects on our retinas. At farther egocentric distances, beyond approximately six meters, binocular disparity is no longer an accurate depth cue because the images falling on the eyes become nearly identical (i.e., the images are at *optical infinity*; Foley, 1967, 1969, 1980). In such cases, the absence of an effective disparity cue causes an underestimation in distance unless it is calibrated by other visual cues, such as familiar size.

In addition to absolute distance cues, relative cues can also influence absolute distance judgments (Gogel, 1963, 1969, 1976; Gogel & Tietz, 1979, 1980). For example, pictorial cues such as occlusion and perspective can provide relational depth information to calibrate depth judgments. For instance, in television programs, pictorial cues such as occlusion, perspective, and motion parallax are used to induce a 3-D perception of an inherently 2-D television screen. It is also possible to use relative depth cues to bias judgments of relative size. For instance, in the movie *Top Gun*, when Tom Cruise is angled towards the screen and Val Kilmer angled away from the screen, observers are biased to think that both actors are similar in height (in actuality Val Kilmer is approximately 18 cm taller; The Internet Movie Database, 2010).

Despite the availability and effectiveness of relative depth cues in the environment, there is limited evidence that multiple relative distance cues work in conjunction to better calibrate distance judgments (Gogel & Tietz, 1980). It appears that cognitive processes rely on heuristics weighting the most available (and generally informative) distance cues to the exclusion of other still-relevant cues. As previously discussed, it also appears that task instructions differentially weight distance cues (Epstein, 1963). In addition to visual cues influencing distance judgments, there are two tendencies of our visual system that also work to calibrate distance judgments: the *equidistance tendency* and the *specific distance tendency.*

The Equidistance Tendency

The equidistance tendency (Gogel, 1963, 1964, 1965a, 1965b, Gogel & Tietz, 1979, 1980) is the propensity to perceive adjacent objects located at different distances to be at the same distance, generally the midpoint between the physical depths of the objects. For example, the equidistance tendency emerges when a person observes how tall office buildings viewed at a distance tend to be grouped along a similar plane, even though they may be several blocks apart. The equidistance tendency is strongest when there are no convergence cues (i.e., when the objects are viewed either monocularly or at optical infinity) and no common relative depth cues. The equidistance tendency is a relatively weak perceptual tendency that is always present but whose influence is often masked or subsumed by the influence of other depth cues (Gogel, 1965, 1963).

The general methodology for eliciting the equidistance tendency involves placing two or more similar objects with different visual angles (e.g., different-sized transparencies of playing cards; Gogel, 1956) in a reduced-cue visual alley and asking participants to view them monocularly. The objects have the same linear size (specified by the familiar size cue) but different angular sizes. While both objects are located at the same distance from the participants, the relative size cues make the object with a larger angular size appear closer. Observers are asked to make judgments about of the depth of each object either by adjusting an adjacent reference disc until it appears at the same depth as each individual object or by providing a verbal estimate of each object's depth.

In a study that investigated the equidistance tendency, Gogel and Harker (1955) found that there was no difference in reference disc depth adjustments between larger and smaller playing cards when the lateral separation between them was 3.7 cm. This result would not be expected if participants were relying solely on the relative size cues, but is instead consistent with the equidistance tendency. When a larger 22.9 cm lateral separation was used, however, the larger disc was perceived as closer. This result is consistent with the relative size cues. Nevertheless, while the larger disc was perceived to be closer, the participants' verbal estimates of the distances were strongly influenced by the equidistance tendency. This finding led Gogel and Harker to conclude that the strength of the equidistance tendency is inversely related to the lateral separation among the objects. This phenomenon is referred to as the *adjacency principle* (Gogel, 1963, 1965).

The Specific Distance Tendency

While the equidistance tendency identifies the observers' inclination to place nearby objects at the same depth, the specific distance tendency (Gogel 1969; Gogel & Tietz, 1973) identifies the observers' propensity to judge objects at a default distance of approximately 1.5 to 3 meters in the absence of absolute depth cues. The specific distance tendency is critical because its effect is observed in all reduced-cue experimental environments. In many experimental conditions, this tendency to perceive objects at a default distance, also referred to as the *egocentric reference distance*, conflicts with the distance specified by the familiar size cue. For example, if the familiar size cue influences the depth judgment of a baseball to be 6 m down a reduced-cue visual alley, then this 6 m judgment conflicts with the 1.5 – 3 m egocentric reference distance. The actual depth judgment will thus be some range between 1.5 – 6 m based on the relative weighting of the familiar size cue with the egocentric reference distance. This unavoidable conflict inherently reduces the effectiveness of the familiar size cue in calibrating distance judgments.

In a series of experiments on the specific distance tendency, Gogel (1969) had observers make distance judgments of a large (5.3° visual angle) or small (2° visual angle) rectangle in a visual alley. The rectangles were located at 3.23 or 6.43 m from the observer. In the full-cue condition, five familiar objects were also placed in the alley at a range of distances spanning 1.22 to 5.49 m. As expected, the reported size and distance of the familiar objects in the full-cue condition conformed to the SDIH. In the reduced-cue conditions, however, observers perceived the rectangles to be between 2.38 and 2.92 m away, regardless of their size or distance. From these results, it appears that the specific distance tendency extends to a maximum of 3 m (Mershon & Gogel, 1975).

Subsequent research validated Gogel's (1969) initial findings. As previously discussed, Tyer et al. (1983) presented observers an electroluminescent object in a reduced-cue visual alley. When the observers were given no depth cues, distance judgments were normally distributed around 2.89 m, a value that is consistent with the specific distance tendency. Similarly, when Park and Michaelson (1974) placed a blank disc in a reduced-cue visual alley, the judged distance was 2.44 m and 2.03 m (expected 1.82 m and 3.64 m, respectively). These distance judgments again were consistent with the range of the specific distance tendency.

The specific distance tendency thus appears to be an automatic process, which may facilitate or inhibit other depth cues depending on the exact viewing conditions. It can be attributed to binocular disparity cues, possibly the resting state of accommodation, which places the farthest objects of focus approximately 2-3 m distant (Gogel, 1969). An application of the specific distance tendency is to provide absolute depth cues in the absence of absolute depth information (Mershon & Gogel, 1975). As will be further discussed, the specific distance tendency is a stronger visual cue than familiar size. Therefore, it tends to mask familiar size effects when the two cues conflict.

The Role of Distance Cues in Size and Depth Constancy

Size constancy is the phenomena by which the same object having different angular sizes at different distances is perceived to be the same size. This was one of the basic applications of the classic SDIH: to show that perceived size should remain constant when perceived distance varied inversely with visual angle (cf. Equation 1). Size constancy is governed primarily by accommodation and convergence at near distances (< 2 m), and by contextual cues such as familiar size and perspective at farther distances (Bishop, 1994). When there are limited perspective cues such as in reduced-cue visual alleys, the specific distance tendency becomes the strongest distance cue, often overriding familiar size cues and distorting size constancy judgments (Gogel, 1969). The evidence previously presented on visual illusions and task instructions are also examples of where size constancy is apparently violated.

While size constancy has traditionally been explained in terms of objects perceived at different distances in the environment, several studies have examined size constancy in terms of the accurate detection of gap size (i.e., the separation between two objects, also known as inter-object distance; McKee & Welch, 1992; Morgan, Hole, & Glennerster, 1990; Badcock & Westheimer, 1985). Thresholds for detecting changes in gap size range from 3 to 6% with disparities larger than .3° of visual angle. These thresholds are also similar to those in line-length estimation tasks (Westheimer & McKee, 1977).

Depth constancy, on the other hand, is the perception of a constant depth between two objects when seen at different distances. Unlike size constancy, depth constancy is governed by the following equation:

$$D_x = \mathrm{R} * D^2 \tag{6}$$

where D_x is perceived depth between two objects, R is the difference in retinal disparity between the two objects, and D is perceived distance to the nearest object. Depth constancy was originally studied using three-dimensional wire form pyramids seen through a lens and mirror to control for accommodation/convergence cues (Bishop, 1994; Wallach & Zuckerman, 1963). Observers made depth judgments by sliding a variable-length rod to the apparent distance between the apex and base of the pyramid. Observers also made size judgments by using the rod to represent the length of a diagonal section of the base of the pyramid to its apex. When convergence and accommodation cues were manipulated, both size and depth were perceived relatively constant when compared to the control stimulus, with approximately 25% deviation from ideal constancy.

Kaufman et al. (2006) further argued that when size and depth constancy are informed by binocular disparity, they utilize the same underlying perceptual mechanisms. At farther distances (>2 m), however, the binocular cues of convergence and accommodation are insufficient to maintain depth constancy. Similar to size constancy judgments, both familiar size and linear perspective act as distance cues to calibrate depth constancy (O'Leary & Wallach, 1980a). Perspective cues, however, have a tendency to cause the perceptual system to overcompensate for a lack of binocular cues causing overconstancy, where apparent size and depth get larger at farther distances (Norman, 2002).

Direct Reports of the Familiar Size Cue

The prior section has examined the role of perceptual cues on distance judgments. Familiar size, however, is a cognitive cue. Assuming that familiar size is an effective cue to calibrate distance judgments, the question then becomes: Does familiar size influence only apparent distance judgments or does it affect the actual perception of distance?

The general methodology for assessing the role of familiar size cues on direct reports of distance typically entails presenting either a single object or two objects side-by-side, and having participants make judgments of object depth (Carlson & Tassone, 1971; Gogel, 1976; Gogel, 1981; Gogel & Da Silva 1987a, b; Gogel & Mertens, 1968; Higashiyama, 1984; Mershon & Gogel, 1975; O'Leary & Wallach, 1980; Park & Michaelson, 1974; Predebon, 1992, 1994). As previously discussed, Carlson and Tassone (1971) compared relative distance judgments between a familiarly-sized cutout of a woman with an unfamiliar similarly-sized rectangular cutout placed at the same distance in a naturalistic scene. Using objective instructions, the familiar object was seen as relatively more distant and shorter than the unfamiliar object. Recall that familiar size effects are promoted under objective task instructions (e.g., judging distance as if measuring with a ruler) and minimized under apparent task instructions (e.g., judging distance as it appears visually). Predebon (1990) replicated and extended Carlson and

Tassone's results along a range of distances. They found that distance judgments were not altered whether the unfamiliar object was a simple rectangle or an irregular shape.

Similarly, Park and Michaelson (1974) asked participants to make metrical verbal estimates and magnitude productions (by re-creating the previously perceived depth in a parallel visual alley) for one of three conditions: they were provided a known size for the disc, they were told that the disc was the size of a familiar object without being given size information, or they were shown a transparency of a familiar object. The correlations between the verbal estimates and magnitude productions were above .93 for all three conditions. In the trials where the transparencies of familiar objects were used and trials where the disc was related to the size of a familiar object, the familiar size calibrated distance judgments. The effect was nevertheless stronger when transparencies of familiar objects were used. When told the size of the disc, however, distance estimates conformed only to the specific distance tendency. It was surprising that relating an unfamiliar object (i.e., the disc) to the size of a familiar object calibrated distance judgments, but being told the size of the unfamiliar object did not. It is possible that being compared with a familiar object generates more useable visualized cues than being told its exact size (i.e., only being provided a *known size*). Thus, the strength of familiar size cues may influence the weight that these cues exercise on distance judgment. In summary, providing a known size of an object is either insufficient to generate a familiar size cue or is insufficient to overcome the conflicting cue provided by the specific distance tendency.

Nonetheless, there were some methodological concerns with Park and Michaelson's (1974) evidence. The stimuli were presented 1.83 m down the visual alley, a distance that is close to the specific distance tendency. It is thus possible that participants accurately perceived the physical location of the stimuli, but that the relative weighting of the specific distance tendency was mediated by an accurately perceived distance. Mershon and Gogel (1975) tested this hypothesis and found support for it when they failed to replicate Park and Michaelson's (1974) familiar size effects. Mershon and Gogel's visual alley differed in that it had a checkerboard floor pattern to assist in distance estimates and it displayed two similar transparencies 7.3 cm apart at a fixed depth of 85.7 cm from the observers. Thus, the physical depth at which the stimuli were presented was much closer than the depth stipulated by the specific distance tendency. Stimuli were transparencies of a stamp (familiar size 2.5 cm) or a university catalog (familiar size 14.9 cm). Both transparencies displayed the same image on a given trial (i.e., stamps or catalogs). Observers accurately reported the familiar size of the stamp and catalog from memory (M = 2.0 cm, 15.6 cm respectively). However, when they were asked to adjust two vertical markers in the visual alley to indicate how they perceived the size of the stamps or catalogs, the participants gave similar size responses to both stimuli (M = 14.6 cm and 13.6 cm, respectively). Similarly, familiar size cues exhibited no significant effect on judged distances, which were consistent with the specific distance tendency. Taking judged distance into account, the perceived size of the stamps and catalogs agreed with the SDIH.

One possibility for the incongruent results of Park and Michaelson (1974) and Mershon and Gogel (1975) is that the former used objective instruction while the latter used apparent instruction. Another possible explanation for the incongruent results could be a conflict among the available cues. If the specific distance tendency (in conjunction with the SDIH) caused the stamps to be perceived 14.6 cm in size, then this conflicted with the familiar or expected size of the stamps (2.0 cm) which could have reduced the influence of the familiar size cue and promoted the size stipulated by the specific distance tendency. In other words, participants may have disregarded the familiar size of the stamps because it did not match the perceived size of the stamps. This incongruence between the perceived size of an object and its familiar size is called an off-sized perception (Mershon & Gogel, 1975). In general, an off-sized perception is generated any time the perceived size of an object (stipulated by its angular size and perceived distance) is different from its expected or familiar size.

Higashiyama (1984) conducted a similar direct report investigation of familiar size cues on size judgments. He examined familiar size cues under both objective and apparent instruction conditions, and under monocular, binocular, and full-cue viewing. Familiar objects included a stamp, a cigarette package, and a book (2.5 cm, 5.7 cm, and 10.5 cm in size respectively). The results showed that apparent instructions produced larger estimates of size than objective instructions. Moreover, richer viewing cues increased the overall size estimates for apparent, but not objective instructions. It appears that, for objective instructions, familiar size was a strong determiner of reported size even in the presence of richer viewing cues. With regard to distance estimates, familiar size significantly influenced distance judgments in accordance with the SDIH under objective instruction. Under apparent instruction, familiar size was an effective distance cue only under monocular viewing. This study confirms that familiar size cues can be an effective tool to calibrate distance, especially under reduced-cue environments.

In a complementary experiment, Higashiyama (1984) asked 90 participants to describe their viewing attitude. Viewing attitudes were classified as apparent (e.g., just visualizing the distance) or objective (e.g., trying to judge distance as if using an imaginary ruler). Forty-two participants reported using an apparent attitude, 30 participants reported an objective attitude, and 18 participants provided responses that could not be classified. Similarly, Bolles and Bailey (1956) found that in the absence of clear instructions, half of the observers adopted an objective attitude and half adopted an apparent attitude. Of Higashiyama's 42 observers who reported using an apparent attitude, 9, 14, and 19 were from the monocular, binocular, and full-cue conditions, respectively. Of the 30 observers who reported using an objective attitude, 14, 9, and 7 were from the monocular, binocular, and full-cue conditions respectively. These results indicate that the richer the spatial cues in the environment, the more likely observers are to take an apparent attitude and limit familiar size cues. Conversely, the more limited the spatial cues, the more likely observers are to take an objective attitude and leverage familiar size cues.

In summary, studies which manipulate familiar size cues, and which involve direct reports (e.g., of sizes, distances and viewing attitudes), have shown that familiar size can be an effective cue to calibrate distance judgments, especially under objective instruction and in reduced-cue environments. However, under apparent instructions, the familiar size cue can come into conflict with the specific distance tendency, which may cause an observer to judge the object as off-sized. Due to the effect of task instructions, it is unclear whether familiar size cues actually affect perceived distance or all distance judgments more generally.

Indirect Reports of the Familiar Size Cue

To better understand the perceptual effect of familiar size cues on distance perception, Gogel (1976) developed an indirect measurement of perceived egocentric distance that did not require explicit reports, which is called the head-motion technique. The difference between direct and indirect measuring techniques is that, for direct measurements such as verbal reports, observers are aware of the goal of the task (e.g., making distance judgments) and are making conscious judgments of the distance. For the indirect head-motion technique, observers are not aware of the goal of the task and are not making conscious distance judgments. Instead, observers report when the motion of a target object appears constant with concomitant movements of the head. In other words, observers report when the object appears to move in the same direction as their head (i.e., there is perceptual stability during head motion). The experimenter then converts this indirect evidence to a distance judgment using predictions from the SDIH.

The head-motion apparatus consists of a mobile "T"-shaped chinrest that allows the observer to views objects from two alternating positions (the edges of the "T") mounted in a visual alley. The object is fixed along a rod attached to a chinrest such that the rod moves with the observer's head. This rod pivots at an adjustable distance. When the object appears to move laterally opposite to the head movement, then perceived distance is farther than the pivot distance. Conversely, when the object appears to move laterally in a similar direction as the head movement, then perceived distance is closer than the pivot distance. Finally, when the object appears to move concomitantly with the head, then the pivot distance equals perceived distance. Different versions of this apparatus allow for the simulation of perceived distances ranging from .8 to 35.5 m. The use of head-mounted apparatus to indirectly measure distance perception has produced consistent and substantially different results than verbal reports.

For instance, Gogel (1976) asked observers to make both verbal and head-motion judgments of the distance of similar-sized transparencies of three familiar objects (a key, sunglasses, and a guitar) whose sizes simulated distances of 63 cm, 185 cm, and 1236 cm respectively. The actual distance of the transparencies was 133 cm. Familiar size cues influenced verbal reports of distance and, to a lesser extent, head-motion responses. Verbal reports of distance were also consistently underestimated by approximately 53% based on baseline distance judgments in a calibration alley. While both verbal reports and head-motion responses exhibited familiar size effects, they were much more pronounced in the verbal reports. The actual size of a guitar is 19.6 times the size of a key, but the transparency of the guitar was reported to be only 10 times the size of the transparency of the key for verbal reports and 1.4 times the size of the key in head-motion responses. This result is especially noteworthy considering that the study was conducted under apparent instructions, which should have reduced the effectiveness of familiar size cues. This underestimation in size may in part explain the participants' underestimation of distance.

To examine the role of the specific distance tendency, an unfamiliar rectangle was also used as a comparison stimulus and placed 133 cm away from the observers. The verbal reports located the rectangle to be at an average distance of 397 cm, whereas the head-motion technique located it at average distance of 281 cm. This is well beyond the rectangle's actual distance from the observer and is consistent with the specific distance tendency acting as an *egocentric reference distance* in the absence of any absolute distance cues. For the other objects (key, guitar, sunglasses), there was a small effect of familiar size on perceived distance, but overall the distances perceived in the head-motion technique were in fact consistent with the 1.5 to 3 m range suggested by the specific distance tendency.

In a follow-up study using verbal reports, Gogel (1981) found similar familiar size effects with familiar rectangular objects (a Reader's Digest and a playing card) and familiar circular objects (a 45 rpm vinyl record and a silver dollar). He did not, however, find any significant familiar size effects using the head-motion technique. He speculated that the objects were not sufficiently different in actual size to generate the desired effect. Finally, McCracken, Gogel, and Blum (1980) used post-hypnotic suggestion to implant familiar size effects on distance perception. The results were similar to previous studies: familiar size effects were facilitated in the verbal reports of distance, but were not significant for the head-motion technique.

Multiple studies have since found converging evidence confirming that the head-motion technique is an effective measure of perceived distance (summarized in Gogel et al., 1985; more recently see Mon-Williams & Tresilian, 1999). Furthermore, familiar size cues have little effect on distance perception, while still significantly influencing distance judgments. This implies that familiar size cues, while an effective cue to accurate distance judgments, are not captured by perceptual processes. To account for the dissociation of direct reports of distance from perceived distance, a two-process theory of size and distance perception has been proposed.

The Theory of Off-Sized Perceptions

While direct reports have identified that familiar size can influence explicit distance judgments, indirect measures of distance perception (e.g., via head-motion) have shown that this cue may only affect distance judgments and not distance perception. When an object's familiar or expected size conflicts with its perceived size (determined by its angular size and distance), an automatic process determines that the object is off-sized (Gogel & Da Silva, 1987a). Applying the SDIH, when an object is perceived larger than its expected size, it must be closer than expected, and conversely when an object is perceived smaller than its expected size it must be farther than expected.

These predictions were first examined in Gogel's (1976) head-motion study that investigated the effect of familiar size cues on distance perception. Remember that participants were asked to make verbal judgments about the distance of a key, a pair of sunglasses, and a guitar positioned in a visual alley. The verbal reports exhibited familiar size effects: the key had a perceived size to familiar size ratio of 3.0, the pair of sunglasses had a ratio of 2.4, and the guitar had a ratio of 0.3. For an object to be judged normal in size, the perceived size to familiar size ratio should be approximately 1.0. Based on the ratio results, both the key and sunglasses were perceived as large off-sized objects, and the guitar was perceived as a small off-sized object. Consequently, the judged distance of the key and sunglasses should be less than their perceived distance, and the judged distance of the guitar should be greater than its perceived distance. These under- and overestimations occurred as expected, but not to the extent predicted by the SDIH.

To account for the discrepancy between the actual perceived distance results and those that the SDIH predict, Gogel and Da Silva (1987a, 1987b) posited a two-process model that dissociates perception from judgment. The primary process is *perceptual* and is captured by the classical SDIH. It is automatic and is not vulnerable to interference. The secondary process is *cognitive* and behaves according to Equation 7:

$$D_c = D\ (S_c/S) \tag{7}$$

where D_c is apparent distance, D is perceived distance, S_c is apparent (e.g., familiar) size, and S is perceived size. This secondary process requires information from the primary process as well as a mnemonic (i.e., representational) component. When apparent size is generated by familiar size, task instructions, or prior knowledge, then it is considered a cognitive phenomenon. Nevertheless, changes in apparent size that are due to optical expansion (i.e., perceived motion in depth) may still be considered perceptual, in that they are governed by the laws of perspective. The perception of motion in depth from discrete images (such as viewing through a tachistoscope), however, can implicate multiple cognitive cues depending on the duration of the inter-stimulus interval. For instance, there may be an early perceptual representation based on perspective cues and early visual processes working on the iconic memory image. This early representation may be elaborated with additional cognitive components based on a representation in visual short-term memory (Vogel, Woodman, & Luck, 2006). When inter-stimulus intervals exceed 200-300 ms, then the resulting trace is wholly within a visual short-term store and not in iconic memory (Sperling, 1960). The role of visual short-term memory will be discussed in the next section.

Equation 7 has described the secondary process in the theory of off-sized perceptions, but it does not describe how size and distance judgments are made. Task instructions have been shown to affect the strength of familiar size cues on distance judgments. This implies that the relative strength given to the primary and secondary processes can be weighted according to task demands. Using a simple weighting approach, Gogel (1987a) has derived the size and distance responses functions as follows:

$$D_r = aD + (1 - a)D_c \quad (8a)$$

$$S_r = bS + (1 - b)S_c \quad (8b)$$

where D_r and S_r refer to distance and size responses, and *a* and *b* refer to the relative weightings of the primary and secondary processes. The relative weightings of *a* and *b* do not need be the same value for a given judgment (e.g., one can differentially weight the role of apparent size and distance when making a size or distance response). For instance, Gillam (1980) found that pictorial cues such as linear perspective modify size judgments without simultaneously modifying distance judgments.

In fact, differential weightings for apparent size and apparent distance may account for many visual illusions and provide an explanation of the Ebbinghaus illusion that is different from that of McCready (1985). Relative size cues could heavily weight apparent size (*b* in Equation 8b) for each of the central circles in the Ebbinghaus illusion. This weighting towards apparent size would influence reported size such that the circle surrounded by the larger circles appears smaller than the circle surrounded by smaller circles. There are two possible causes for the lack of perceived depth change of the central circles. The first possibility is that the specific distance tendency could decrease the weighting of apparent distance (*a* approaching 1 in Equation 8a) for each of the central circles. In this case, the reported distance of the central circles would be weighted towards their perceived distance. The second possibility is that the specific distance tendency, as a strong distance cue, could be more heavily weighted than the relative size cue for apparent distance as opposed to apparent size. In this case, the reported distance of the central circles would be weighted towards the egocentric reference distance supplied by the specific distance tendency (Gogel 1987a). This egocentric reference distance is similar for each of the circles. Thus, the reported depth of the circles would be unchanged.

In the absence of task instructions, one of the most heavily weighted cues in reduced-cue environments is the egocentric reference distance (Gogel & Da Silva, 1987b). The egocentric reference distance is the approximately 1.5 to 3 meter reference depth provided by the specific distance tendency. As previously discussed, this tendency has been correlated with the resting state of accommodation. The presence of the egocentric reference distance generates a conflict between the distance determined by the specific distance tendency and the distance determined from familiar size cues, which then increases the likelihood of an off-sized perception occurring. For instance, if an object's perceived size specified by the egocentric reference distance and the SDIH conflicts with the object's familiar size, then an off-sized perception will likely occur. This off-sized perception calibrates perceived distance such that large off-sized objects tend to appear closer than the egocentric reference distance and small off-sized objects tend to appear farther. This accounts for apparent size-distance paradox of the moon illusion. If objects along the horizon cause the moon to be perceived as a large off-sized object when compared to its zenith size, then the horizon moon will also tend to appear to be closer than at its zenith.

Task instruction also biased responses, such that apparent instruction more heavily weights responses using information from the primary perceptual process while objective instruction more heavily weights responses using information from the secondary inferential process. Gogel and Da Silva (1987b) presented more evidence in support of the role of task instructions in off-sized perceptions. When judging the size of a blank rectangle versus a normal-sized playing card at various distances in a reduced-cue environment, it was found that the reported size and distance of the blank rectangle was not significantly affected by either task instruction or different physical distances. This is consistent with a lack of familiar size to calibrate judgments (i.e., there is no comparison object in memory to generate an off-sized perception). The reported size of the playing card was constant under objective instruction, but its reported size diminished at relatively farther distances under apparent instruction. This result suggests that apparent size was more heavily weighted under objective instruction and perceived size more heavily weighted under apparent instruction.

Consistent with the egocentric reference distance, distance judgments of the rectangle at different physical distances were not significantly different, however. Under both apparent and objective instructions, there was a linear trend to report relatively farther physical distances as slightly farther. This trend occurred because under both task instructions an off-sized perception was generated. Consequently, this off-sized perception emerged because the apparent (i.e., familiar) size of the object remained unchanged while the perceived size of the object varied with the physical distance in accordance with the SDIH. More specifically, the ratio of apparent size to perceived size increased as physical distance increased. This caused a "small" off-sized perception as physical distance increased, resulting in a "farther" distance judgment. The differences in distance judgments were not significant because the egocentric reference distance was more heavily weighted than familiar size cues, subsuming the distance judgment specified by familiar size cues.

To summarize, the theory of off-sized perceptions postulates a two-process model for size and distance judgments. The primary process is perceptual and is consistent with the classical SDIH. The secondary process is cognitive and involves memory and prior perceptions. A weighting function mediates the effectiveness of the secondary process when making distance judgments. An advantage of the theory of off-sized perceptions is that it accounts for the dissociation between mainly perceptual responses (as seen in the head-motion technique) and direct responses (as seen in verbal reports). This dissociation and the introduction of differential weightings of the secondary process for size and distance judgments can also account for certain visual illusions. The following section examines some of the limitations of the theory of off-sized perceptions.

Limitations of the Theory of Off-Sized Perceptions

The theory of off-sized perceptions provides an intriguing description of the results of common visual illusions and the apparent dissociation between perceptions and cognitive responses for size and distance judgments. This theory, however, does not provide an in depth explanation into the mechanisms required to generate and mediate cognitive influences on size and distance perceptions. In particular, a limitation of the theory of off-sized perceptions is that it does not fully explain why objective and apparent instructions affect size judgments while not affecting distance judgments (Predebon, 1992). The weighting functions (Equations 8a and 8b) are structured to allow the weights of perceptual and cognitive processes on size responses to be different than the weights on distance responses, but there has been very little explanation of how or why this weighting occurs. A possible explanation is that the egocentric reference distance has no size equivalent (i.e., there is no evidence of a corresponding reference size or specific size tendency). Therefore, distance judgments may be systematically more heavily weighted to the always-present egocentric reference distance.

Another limitation of the theory of off-sized perception is that familiar size is underspecified as a cue, that is, variations in the token size of an object are not taken into account when examining the role of familiar size on distance judgments. Token invariant objects are things like playing cards, bicycles, and basketballs, which have very little physical variation in physical size (e.g., from one playing card to the next). Token variable objects are things like chairs, lamps, plants, and televisions, which display broad size variations within each category. Haber and Levin (2001) found that when objects are placed at various distances in a full-cue natural scene (i.e., a large grassy field), observers made more stable object size judgments with token invariant objects than token variable objects. In addition, the familiar size of token invariant objects better calibrated distance judgments than token variable objects. Finally, only token invariant objects significantly improved (i.e., calibrated) distance judgments at farther distances (50 to 100 meters). In fact, distance judgments for token variable objects were no better than for unfamiliar objects. Thus, Haber and Levin's (2001) results strongly suggest that the effectiveness of size and distance judgments based on off-sized perceptions may be limited by token variability and a particular observer's prior experience with an object.

The Incompleteness of Dual-Process Models

Gogel and Da Silva (1987a) argued that size and distance perception is governed by two processes. The primary process is perceptual and operates in accordance with the size-distance invariance hypothesis. The secondary process is cognitive and is influenced by familiar size cues, prior experience, and attention. Importantly, off-sized perceptions increase the weighting of the secondary process in generating a size or distance judgment. The nature of these processes, however, is underspecified. For instance, the secondary "cognitive" process appears to be more of a catch-all for any factors which influence verbal reports, but not the head-motion technique (Gogel, 1981, 1998; Gogel et al., 1985; Gogel & Da Silva, 1987b). The exception to this characterization is the perceived change in size due to optical expansion, which is seen both as causing an off-sized perception and being part of the primary perceptual process.

Instead of size and distance perception being articulated as two distinct processes, it is probably more accurate to define perception as occurring through two levels of processing, regardless of the actual processes or mechanisms involved (Norman, 2002; Gregory, 1997; Baird & Wagner, 1991). In particular, the primary perceptual "process" should encompass the set of bottom-up visual mechanisms such as those governing accommodation and convergence; edge detection and orientation; and possibly, those that yield the Gestalt laws of grouping and perspective. These mechanisms correspond to patterns of neural firing occurring in the primary visual and entorhinal cortices (Fyhn, Molden, Witter, Moser, & Moser, 2004; Kosslyn, Thompson, Gitelman, & Alpert, 1998). Bottom-up mechanisms are also involved in automatically determining the salience (i.e., uniqueness and relevance) of incoming sensory perceptions (Knudsen, 2007). These mechanisms encode and process the initial visual information from the optical nerve, and result in the perceptions captured predominantly by the classical SDIH, where perceived linear size is determined from angular size and perceived distance.

In addition to the bottom-up primary process, the secondary cognitive "process" would be better identified as the set of top-down memory and attention mechanisms including prior experience, familiar size, and task instructions. Top-down mechanisms regulate and manipulate signals from the bottom-up processes, selecting which signals (e.g., cues) are forwarded to memory and decisional mechanisms (Knudsen, 2007). These mechanisms require visual information from the bottom-up processes to work. Thus, the secondary process should be seen as roughly serial in nature. For instance, general features of objects in the scene need to be processed (i.e., the early phase of object recognition) before familiar sizes of the objects can be recalled from memory. These cognitive mechanisms result in the judgments captured by off-sized perceptions, including familiar size cues. In addition, because top-down mechanisms regulate incoming bottom-up signals, the two-process model is analogous to a recurrent network (Anderson, 1977; Dehane, Sergent, & Changeau, 2003).

Modifying the primary/secondary process distinction to be one between bottom-up and top-down processing still does not capture the mechanisms involved in weighting the judgments made by each process. This weighting is the kind of mechanism influenced by task instructions. In addition, because the "primary" representation appears to be accessible throughout the decision-making process (e.g., under apparent instructions), there appears to be some sort of gating process which splits (or maintains) the "primary" representation. One stream gets modified by top-down cues like familiar size, while the other stream is sent directly to a decision process. Finally, there needs to be a decision/weighting function which determines the relative weighting of the primary and secondary representations. An example process model is shown in Figure 5.

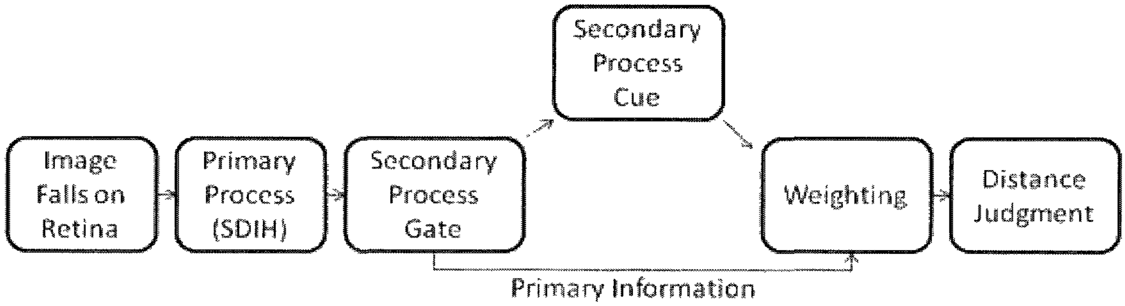

Figure 5. Sample process model minimally required to account for the predictions of the theory of off-sized perceptions.

There is a debate whether angular size is directly accessible by observers or whether it is only indirectly available through judgments of perceived size. Multiple studies have shown that, under projective instructions, observers are able to accurately judge the angular size of objects (McKee & Welch, 1992; Carlson, 1960; Gilinsky, 1955). As distance cues increase in the environment, however, even angular size judgments are prone to error based on distance perception and familiar size (Kaufman et al., 2006; Murray et al., 2006). This implies that angular size, per se, is not directly accessible. Instead, the available representation is perceived size consistent with the classical SDIH.

One question regarding the separation between bottom-up and top-down processes is which process best captures relative size cues? Gogel (1956, 1963, 1969, 1998) argued that relative size cues are perceptual because relative size influences distance judgments using the head-motion technique. Supporting this interpretation, relative size as a cue to size and distance perception only requires "early" visual information such as binocular disparity to make a judgment; it does not require familiar size or other memory processes. For instance, an observer does not need to know the average width of a car lane to judge that a snow-covered highway is two lanes wide.

From this example and evidence from the head-motion technique, it appears clear that relative size cues are bottom-up perceptual processes.

If bottom-up and top-down processes function like a recurrent network, however, then the effectiveness of relative size cues could still be increased by top-down processes, such as familiar size cues. For instance, the average car lane in a city is approximately two cars wide, with space for one car parked and one car circulating. Perceiving distance as two cars wide, however, limits the utility of the judgment. How could an observer compare her "two cars-wide" distance with a judgment from another scene, such as perceiving his kitchen as "five stoves-wide"? Without a common frame of reference to form a common metric, relative size cues have a limited effectiveness across scenes. For instance, if a student is viewing an apartment and is trying to see if a bed will fit in a room, then perceiving that the room is three doorways-wide provides insufficient evidence to make an accurate judgment. Familiar size, however, can improve the effectiveness of relative size cues by providing an absolute distance metric. Returning to the "car and stove" example, assuming that the average car is approximately 1.75 m wide and the average stove is 70 cm wide, then both relative size cues indicate that the respective perceived distances are approximately 3.5 m wide. Thus, the perceived distances of the car and stove metrics are similar. This example highlights how the effectiveness of relative size cues can be increased using top-down mechanisms, namely familiar size cues.

In summary, the theory of off-sized perceptions as described by Gogel and Da Silva (1987a) does not describe the kinds of mechanisms required to generate and maintain two representations. In actuality, the two-process theory is best described as a two-representation theory with a "primary" representation based on early visual processes such as visual angle (i.e., angular size) and the laws of perspective, and a "secondary" representation derived from the primary representation but influenced by top-down influences such as familiar size effects.

Extending the Theory of Off-Sized Perceptions

Despite several features which are underspecified, the theory of off-sized perceptions has been shown to be an effective tool in describing how observers generate size and distance judgments. The majority of the evidence used in developing the theory of off-sized perceptions, however, has been based on egocentric distance judgments, generally to a single object in a view. Consequently, the theory's ability to predict exocentric distance judgments is not known. A substantial difference between egocentric and exocentric judgments is that while only two points of reference are necessary to make an egocentric judgment, three points of reference are necessary to make an exocentric judgment (object 1, object 2, and the observer). As in egocentric judgments, familiar size cues may be present. There are also relative size cues (the relative sizes of the two objects, and possibly their inter-object distance). A first step in extending the theory of off-sized perceptions is to examine whether off-sized perceptions are consistent with judgments of lateral separation (i.e., gap or inter-object distance along the frontoparallel plane).

Depth constancy involves a similar judgment of inter-object distance, but this separation is in depth rather than in width. A subset of depth constancy judgments is the phenomenon of gap constancy. In gap constancy, observers judge whether they can step across a gap at different widths (Jiang & Mark, 1994). An observer is asked to stand on a fixed ledge (e.g., a table) while another ledge is adjusted until it is at a width where the observer judges whether she can confidently step across the gap. The judged crossable distance of the gap across trials is an indirect measure of depth constancy. At farther gap depths, participants tended to underestimate whether the gap was crossable. Interestingly, a similar result was found when toads were tested using an analogous paradigm (Lock & Collett, 1980). Furthermore, when the depth at which the participants could fall increased, judged crossable distances were further underestimated. This result may have been partially due to "cognitive" factors such as fear of injury for deeper gaps. Nonetheless, in a similar reduced-cue variant, gaze position was sufficient to alter gap judgments. In particular, downward vertical shifts in gaze position (such as those seen in looking down the depth of a gap) caused significantly more underestimation. Sobel and Collett (1991) found, however, that vertical disparity does not influence depth judgments when accommodation and convergence cues are available.

To determine whether depth constancy judgments are in agreement with the theory of off-sized perceptions, it is important to determine if size and depth constancy judgments are both influenced by similar cues. As previously discussed, Wallach and Zuckerman (1963; O'Leary & Wallach, 1980b) found that perspective cues influenced size and depth constancy. Similarly, O'Leary and Wallach (1980a) examined the role of both familiar size and perspective in depth constancy, comparing the relative depth of a Canadian dollar bill and a white disc. The bill could be normal-sized or scaled to be .72-sized. The depth between the bill and the disc was a fixed 1 cm, and they were located at a distance of 75 cm from the observers' eyes. Familiar size significantly influenced depth judgments The effect only exhibited partial depth constancy (M = 1.71 cm; expected 2.22

cm), however. Interestingly, in a similar study by Rivest, Ono, and Saida (1989), one participant without knowledge of the familiar size of Canadian currency did not exhibit familiar size effects on depth judgments.

O'Leary and Wallach (1980a, 1980b) also examined the role of linear perspective on depth judgments. Perspective cues were stronger at farther viewing distances, where there were more pattern/texture cues to override binocular cues of accommodation and convergence (which were altered using glasses). Interestingly, much like previously-presented issues with the perspective size constancy explanation for the Muller-Lyer illusion (Gregory, 1963; Howe & Purves, 2005), it appears that perspective cues, or at least their application in size and depth constancy, is learned. O'Leary and Wallach (1980b) used a prism to control for perspective distance cues, and were able to train observers to reduce depth constancy judgments by 20% after exposure. Intriguingly, the notion that perspective cues are learned and can be overridden through training implies that the laws of perspective are in some sense "cognitive" (Bradshaw et al., 1996). Consequently, any learned process (i.e., not innate) would be considered cognitive (thus not perceptual) under this interpretation. Gogel, however, considers perspective cues to be perceptual in that they influence head-motion judgments (Gogel & Tietz, 1980; Toye, 1986;).

There is evidence that egocentric distance judgments and exocentric judgments of lateral separation utilize similar processes. Sterken et al. (1999), for instance, used a change detection task to determine whether egocentric distance and lateral separation information is independently stored in visual memory. Participants were presented a source image for 150 ms consisting of a single dot within a circle. After a 500 ms interval, a similar target image was presented. There were four possible conditions: the target image was the same, the dot was displaced, the circle was displaced, or both the dot and circle were displaced. The two groups of participants were asked to execute a same-different task: one group responded whether the target image had been displaced compared with the source image (an egocentric displacement), and the other group responded whether the dot was displaced relative to the circle (a lateral displacement). Results determined that accuracy for egocentric and lateral displacements were similar overall (.70 and .74 respectively). However, having a co-occurring lateral displacement (i.e., the condition where the circle was displaced) reduced the accuracy of egocentric judgments below-chance levels. Similarly, having a co-occurring egocentric displacement (i.e., the condition where both the circle and dot were displaced) reduced the accuracy of judgments of lateral separation to at-chance levels. This interference between egocentric and lateral separation information indicates that egocentric distance representations and representations of lateral separation are correlated. Similarly, research on spatial scene perception and navigation has shown that current egocentric information interferes with the generation and recall of exocentric representations (Klatzky, 1998; Mou, McNamara, Valiquette, & Rump, 2004; Presson & Montello, 1994).

If lateral separations (i.e., inter-object distances) are processed the same way as object size (i.e., the space between objects is effectively treated as a "gap-object"), then similar processes will be in play for both egocentric and exocentric distance judgments. An observer should perceive the space between two objects the same way as the size of a single object (see Figure 6). A comparison of the mechanisms involved in exocentric distance perception and perceived size further supports the position that there are common processes for egocentric and exocentric distance perception. Assuming that both reference objects are at the same depth, exocentric distance perception is expressed by Equation 9:

$$D_x = \mathrm{D} * \tan(\theta) \tag{9}$$

where D_x is perceived lateral separation, D is perceived egocentric distance, and θ is visual angle. Rearranging the original SDIH (from Equation 1) to measure perceived size:

$$S = \mathrm{D} * \tan(\theta) \tag{10}$$

Equation 10 has shown that perceived size (S) is also determined by perceived depth (D) and visual angle (θ). Substituting Equation 9 into Equation 10, it can be seen that exocentric distance (D_x) is expressed in the same manner as perceived size (S).

If the processes involved in assessing lateral separation and perceived size are similar, then according to the theory of off-sized perceptions, judgments of lateral separation can be affected by relative size and familiar size cues. In fact, when both objects are at equal depth from the viewer (on a plane perpendicular to sight), relative and familiar size cues could have a greater impact on exocentric perception than egocentric perceptions, because there is no mitigating conflict with the specific distance tendency. This idea could account for the strong influence of relative size cues on the Ebbinghaus illusion and the specific distance tendency could help account for the lack of apparent distance change in the central circles.

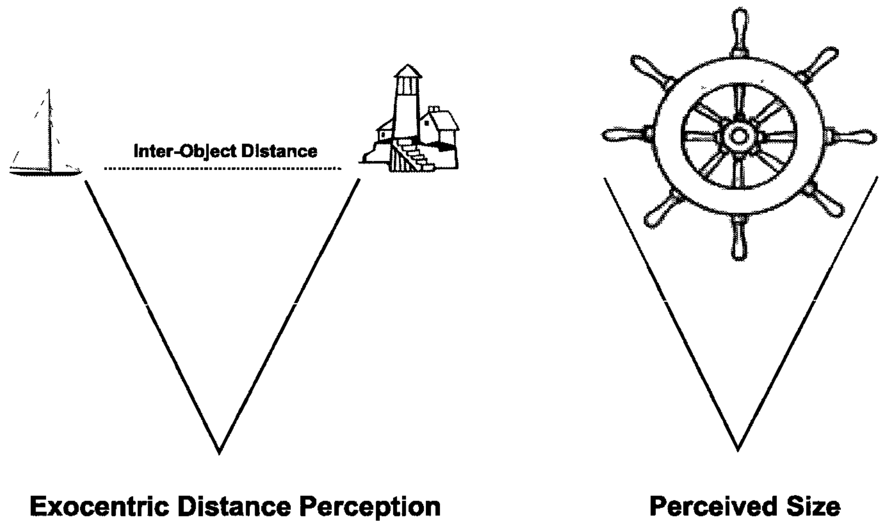

Figure 6. Illustrations showing how exocentric distance perception may be similar to size perception. In both examples, an observer is making a judgment based on visual angle and relative depth to a target. The difference is that for exocentric perceptions the target is empty space (the inter-object distance), while for perceived size the target is the object.

To date, empirical research has not examined familiar size effects on judgments of lateral separation. There is evidence, however, that relative and familiar size cues affect exocentric distance judgments. Evidence from the moon illusion and Ebbinghaus illusion has illustrated that concurrently perceived nearby objects affect the size judgment of a target object (Baird et al., 1990; McCready, 1985). There is also evidence that an object's perceived size and distance are influenced by the size and distance of other objects that have recently been the focus of attention (Gogel, 1998; Makovski & Jiang, 2008). Similarly, in Sterken et al. (1999), for example, when both the dot and circle were equally displaced (changing egocentric distance but not lateral separation), participants were unable to detect the change above chance levels. This change blindness (Intraub, 1997) suggests that exocentric distance judgments do not just rely on a comparison of perceived size determined from visual angles (the primary process in the theory of off-sized perceptions), but that they also rely on relative and familiar size cues.

To conclude, I have argued in this section that judgments of lateral separation are processed in a similar way to object size judgments in accordance with the SDIH. However, there are different cues available to judgments of perceived size as opposed to lateral separation. For instance, there is unlikely to be information about the familiar size of a lateral separation-object because there are rarely familiar inter-object distances. That being said, the familiar sizes of objects bracketing the separation could have an effect on the perception of the separation. In all, if lateral separations and perceived size are processed similarly, it would suggest that the theory of off-sized perceptions is extendable to judgments of lateral separation. To study this hypothesis, the following section argues for the adoption of a change detection methodology based on Gogel's (1998) studies on optical expansion to judgments of lateral separation.

Investigative Approach

Judgments of lateral separation require the presentation of larger visual angles than egocentric distance judgments. Egocentric judgments only need a viewing environment roughly the width of the object currently under perception, but exocentric judgments require an environment roughly the sum of the widths of the inter-object distance and both reference objects. These larger visual angle requirements pose a methodological challenge and make traditional visual alleys impractical. One solution is to use naturalistic scenes (e.g., an outdoor field: Levin & Haber, 1993; Matsushima et al., 2005). However, they provide very limited control over confounding relative and familiar size cues present in the environment (e.g., nearby trees, clouds near the horizon, other reference stakes in the ground, etc).

Another solution to this methodological difficulty is to present the stimuli to be used in the comparison judgments successively. It has been shown that relative and familiar size cues are equally effective under successive or simultaneous presentation (Gogel, 1964). Gogel (1998; Gogel & Eby, 1997; Swanston & Gogel, 1986) developed an optical expansion task to examine the role of off-sized perceptions in apparent motion. Optical expansion and contraction of an object's apparent size creates apparent back and forth motion in depth. Imagine the perception of motion to be like a series of pictures. The change in size of an object between successive pictures is a relative size cue (Gogel, 1964). However, the initial presentation[2] of the object at the beginning of the expansion acts like a standard size (i.e., a familiar size) for subsequent perceptions in successive pictures (Swanston & Gogel, 1986). Observers will thus judge that a given object is expanding or contracting across successive pictures; they will not claim to see a chain of different objects. These expansions or contractions cause the given object to be perceived as off-sized, which then modifies judged depth in accordance with the SDIH (Gogel & Da Silva, 1987a). However, this off-sized perception is considered perceptual because it occurs both for verbal reports and for head-motion responses of distance. This is due to the fact that relative size (a perceptual cue) acts as the familiar size cue. Under this interpretation, a particular interaction of familiar size and relative size either simulates or instantiates the mechanisms involved in the laws of perspective.

While the successive presentation of stimuli resolves some of the difficulties associated with larger visual angles, the optical expansion methodology focuses on the cue of apparent motion, not lateral separation. When stimulus display times are

[2] In a reduced-cue environment, the initial perception of depth during an object's first presentation is consistent with the egocentric reference distance (Gogel, 1998).

lengthened to eliminate the perception of motion, the resulting methodology bears striking resemblance to the one-shot change detection methodology (Phillips, 1974). It may be appropriate then, to integrate the change detection methodology and Gogel's optical expansion paradigm. The following section examines the one-shot change detection methodology and suggests alterations to adapt this method to investigating judgments of exocentric distance.

The One-Shot Change Detection Methodology

Change detection tasks have traditionally been used to study visual attention. They are constructed to determine how likely an observer can detect a change between two successively presented images or to assess how long an observer will take to detect a change (Simons & Rensink, 2005). There are different versions of the task; the one-shot change detection task will now be the object of a short review.

The one-shot change detection task was originally used by Phillips (1974) to distinguish the effects of sensory persistence and visual short-term memory. In the original one-shot methodology, a source array of squares was presented on a computer screen for one second. After a brief pattern mask was shown, a target array was presented and participants were required to perform a two-alternative forced-choice same/different judgment. When the masking interval between the source and target arrays exceeded 100 ms, response accuracy diminished and response times increased. This evidence was used to distinguish between a rapidly degrading "iconic" visual code prone to masking effects and a visual short-term code which is not prone to masking. Generally, one-shot change detection has been used to detect the proportion of observers who detect a change. However, response times are also a valuable tool for providing evidence regarding the possible influence of different processes when comparing accurate responses (hits) with erroneous responses (misses, false-positives, and false-negatives). For instance, when response times are higher for correct responses than for incorrect responses, it may be inferred that observers are adopting a speed-accuracy tradeoff.

Change detection tasks have already been used to study a variety of cognitive phenomena. For example, Vogel, Woodman and Luck (2001, 2006) have used one-shot change detection to measure the time-course for consolidation of features in visual working memory. More relevant to the current research, Treisman and Zhang (2006) used a change detection task to test participants' memory of object locations.

Change detection tasks are not entirely dissimilar from psychophysical discrimination tasks (Kaufman et al., 2006; McKee & Welch, 1992; Morgan et al., 1990). Their motivation, intended results, and methods of analysis are generally different, however. This is reflected in differences in stimulus presentation and pattern mask content and durations. Discrimination tasks use the method of constant stimuli or method of adjustment to determine perceptual boundaries of changes in features. For instance, McKee and Welch's discrimination task had observers perform horizontal gap discrimination between two vertical lines, known as the method of single stimuli. Participants were presented with a single image and had to make a forced-choice judgment whether the stimulus was greater or lesser than the mean of the range of possible stimuli. One-shot change detection tasks, however, are generally used to measure attentional or representational differences, and not necessarily perceptual limits. As such, presentation times are generally longer for change detection tasks (> 750 ms) than for stimulus discrimination tasks (~150 ms), so that as many features as possible of the stimulus or scene can be apprehended. In addition, change detection tasks tend to use masks instead of inter-stimulus intervals or fixation points to eliminate sensory traces from iconic memory and facilitate a comparison between a current percept and a representation in visual short-term memory.

The previous examples highlight how the change detection methodology is relevant to the investigation of size and distance perception. To summarize, the one-shot change detection task is a viable methodology to study size and distance perception. Gathering both accuracy and response times can help determine what heuristics observers use when making judgments of size and distance. The next section will identify how the change detection paradigm can be adapted to Gogel's optical expansion task to examine judgments of lateral separation.

Extending the Change Detection Paradigm

The successive presentation of images in the change detection task is similar to the methodology that Gogel (1998; Gogel & Eby, 1997) used to study optical expansions. In both cases, successive presentations of similar images are used to study how participants detect changes. Extending the one-shot change detection task to examine familiar size cues to exocentric distance perception involves the manipulation of object size and inter-object distance between image presentations. The objects used in this thesis were derived from the two-dimension square stimuli used in Gogel (1998) and Ritter (1979). Recall that Gogel (1964, 1998) determined that the perceived size of an object in the initial presentation of a trial serves as a standard (i.e., familiar size) to be compared with an object in a subsequent presentation. Thus, familiar size does not require multiple presentations and a long-term memory trace, but can be generated on each trial. Also, the size of nearby objects serves as a relative size cue as seen in the Ebbinghaus illusion (Gogel, 1965). Thus, the objects in the source image serve as a familiar size cue to compare against the objects in the target image. Furthermore, if the lateral separation is judged similar to perceived size, then the size of the objects will also be relative size cues in the judgment of inter-object distance.

Both size constancy effects (e.g., familiar size cues) and the results from optical expansion indicate that observers will judge the objects in the source and target image to be the same objects even if their size is different. If object size is changed in the target image, then the objects should be perceived as off-sized. In terms of the theory of off-sized perceptions, this perception of the objects as off-sized will promote the effectiveness of the secondary process resulting in a relatively higher weighting to the relative size cue as opposed to relative visual angle (as predicted solely by the SDIH). Thus, if the ratio of object size / inter-object distance remains constant, it is likely that inter-object distance will be judged to be the same even though both the perceived size of the objects and inter-object distance may be different. If observers instead judge lateral separation using visual angle (Levin & Haber, 1993; Matsushima et al., 2005), then any change in inter-object distance should be accurately detected irrespective of changes in object size.

This combination of relative size and familiar size is similar to (or an instantiation of) the effect of linear perspective in two-dimensional drawings (see Figure 7). Normal perceptual cues of accommodation and convergence are fixed to the plane of the paper, so the only "perceptual" cues to instantiate the laws of perspective are the detection of primitive features such as line, orientation, texture gradient, and luminance detection.

Other cues which may inform a linear perspective transformation (i.e., scaling an image by zooming in) include the detection of familiar objects as off-sized and the presentation of two similar objects appearing along a different vertical plane (simulating a change in height or a change in depth).

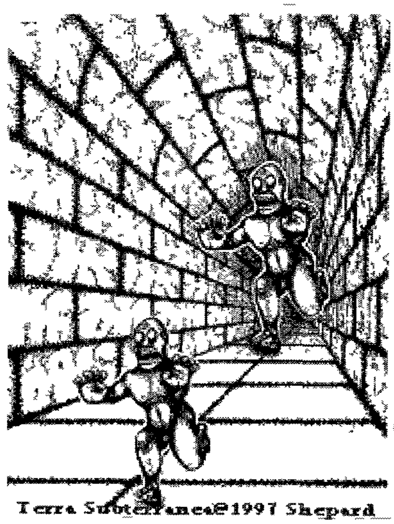

Figure 7. Perspective acts as a size cue. This use of perspective is considered an unconscious inference outside the domain of psychophysics. Image reproduced from "The Motion Aftereffect" (1998, p.505). Mather, G. Verstraten F., Anstis, S. (eds). MIT.

Recall that the judgment in one-shot change detection tasks is generally a two-alternative forced-choice same/different (detect a change or not) response. The current thesis, however, involves more than just a manipulation of lateral separation. It also involves determining the effect of changes in object size on the perception of separation. To accomplish this goal, the same/different response used by Predebon (1990) and Carlson and Tassone (1971) was expanded to a three-alternative closer/same/farther distance judgment. Using this three-alternative judgment made it possible to examine not only observers' ability to detect a change, but also whether or not a change in object size and/or inter-object distance resulted in a particular change in perception (e.g., closer or farther). For example, increasing object size might cause the objects to be judged as closer together due to the relative size cue, in a manner analogous to the Ebbinghaus illusion. In that illusion, larger nearby objects can cause a central object (or a central gap in the current research) to appear relatively smaller than if smaller nearby objects surround a similar-sized central object or gap.

In addition to judgments of relative change, two of the current experiments assessed distance representations using a distance reproduction response similar to that employed in the method of adjustment: participants dragged the mouse to recreate a previously perceived exocentric distance. This distance reproduction response is similar to the responses from Swanston and Gogel's (1986) optical expansion study, where observers manually adjusted two posts to recreate the size of a line perceived at the beginning of an optical expansion. One post was fixed while the other post was adjusted by the observer. Gogel and Harker (1955) also used a similar methodology to judge relative depth by having observers reproduce the depth of an object using a dial to adjust a reference pointer down a visual alley.

The advantage of using distance reproduction is that it is possible to examine quantifiable changes in the perception of inter-object distance. For example, if the relative size cue is the predominant heuristic for exocentric distance judgments, then increasing the size of the objects by 20% should result in the inter-object distance judgment also being increased by 20%. On the other hand, if the specific distance tendency is a conflicting cue (like it is in egocentric distance judgments), then increasing the size of the object by 20% should result in an inter-object distance judgment increasing by a smaller proportion. Thus, distance reproduction is useful to gauge the relative impact of cues implicated in the theory of off-sized perceptions.

Beyond examining patterns of responses, change detection methodologies also allow for the analyses of response time data. Patterns of response times based on whether observers detect the changes in object size and/or inter-object distance can determine the differential impact of relative size cues and the specific distance tendency. For example, changing object size might increase response times more than changing distance because changing object size implicates the familiar size cue (when object size changes) in addition to the specific distance tendency (which is always present).

In summary, applying a change detection methodology to the stimuli from Gogel's (1998) optical expansion studies can aid in extending the theory of off-sized perceptions to judgments of lateral separation. Using both a three-alternative forced-choice response to measure relative judgments and a distance reproduction response to measure quantifiable judgments will provide evidence towards the potential extension of the theory of off-sized perceptions to exocentric distance judgments. In addition, gathering response times can further support serial (or at least differential) processes involved in perceived versus inferred changes in size and inter-object distance. The next section will examine some hypotheses about how the theory of off-sized perceptions can extend to judgments of lateral separation.

Hypotheses

In the previous sections, I argued that inter-object distances may be processed as if the distances were objects. This implies that the perception of lateral separation may be described by the theory of off-sized perceptions. On this view, several hypotheses can be made about how changes in object size and/or distance should affect judgment accuracy and distance reproduction accuracy.

To begin, all accuracy comparisons in the one-shot change detection tasks will be compared against baseline accuracy rates. Baseline accuracy is derived from the subset of trials in which size and distance remained unchanged across the source and target images (i.e., *no-change* trials). In no-change trials, there is no change in the familiar size of the objects and no change in separation between the objects, thus no off-sized perception of the objects or separation should occur. In trials where only inter-object distance changes (i.e., *distance-change* trials), the perception of a change should be consistent with both the relative size cue (e.g., ratio of inter-object distance to object size has increased) and the visual angle cue (e.g., angle subtended by the inter-object distance). For instance, if inter-object distance is increased by 20%, then both the visual angle and the ratio of visual angle to perceived size of the object will be increased by 20%. Because there is no off-sized perception of object-size (no secondary inferences triggered), the accuracy on distance-change trials should be similar to that on the baseline no-change trials.

Consistent with egocentric distance judgments, changes in object size between the source and target images should cause the objects to appear off-sized and bias the secondary process that calibrates distance judgments. Thus, in trials where only object size changes (i.e., *size-change* trials), such a change should impact the relative size cue (e.g., ratio of the inter-object distance to object size). Increasing object size should influence observers to inaccurately report that the inter-object distance has decreased. Similarly, reducing object size should cause a small off-sized perception influencing observers to inaccurately report that the inter-object distance has increased. The off-sized perception should thus influence participants to make incorrect distance judgments in the size-change trials, lowering accuracy relative to baseline no-change trials. The predictions of this thesis are in contrast to the position that visual angle is the predominant cue for general exocentric distance judgments (Levin & Haber, 1993; Matsushima et al., 2005), which would argue that changes in object-size should not influence the judgment of inter-object distance and thus not be characterized by reduced accuracy.

In theories which emphasize the weighting of visual angle (i.e., angular size) in the perception of lateral separations and exocentric distances, when object-size and inter-object distance change in the same proportion (i.e., *congruent change* trials), it would be predicted that observers accurately detect the change in visual angle. On the other hand, the theory of off-sized perception predicts that observers would tend to judge the distance to be the same between the source and target images. Even though the visual angle of the inter-object distance changes, the relative size cue comparing the ratio of the size of the objects to the inter-object distance remains unchanged. Conflicting cues between relative size and visual angle should also reduce accuracy relative to baseline no-change trials.

There is, however, another interpretation of the above size and distance changes. It is possible that observers are using changes in relative object size to scale the image consistent with the laws of perspective (Gregory, 1963). The results would be similar to those predicted from the theory of off-sized perceptions. Nevertheless, there are reasons to believe that the laws of perspective would not be sufficient to generate size-constancy between the source and target images. First, in the reduced-cue environment, object size is the only cue to a change in perspective. Thus, in order for size constancy to occur, the change in object size has to be perceived (analogous to being perceived as off-sized). Furthermore, with longer pattern mask durations, there should be no change in depth due to apparent motion. As the distance of the display is not varied, cues of accommodation and convergence provide a consistent depth judgment (assumed to correspond to the actual distance of the computer monitor influenced by the specific distance tendency).

Assuming that a perceived change in object size does heavily weight (or implicate) the laws of perspective, these laws may be seen as working as a function of (rather than a competitor to) the theory of off-sized perceptions. The fact that size and depth constancy is generally only partial, ranging from complete constancy to only 15% of expected values (McKee & Welch, 1992; Kaufman et al., 2006), implies that some weighting or accumulator process is determining the degree of size constancy (cf. Figure 5). This kind of weighting function minimally implies some top-down influences consistent with a dual-process model. Even Gregory (1963, see also Gregory, 1997) argues that there are two processes implicated in perspective-based size constancy: a primary perceptual process based on perceptual "primitives" implicated in the laws of perspective and a secondary process based on apparent distance and influenced by prior knowledge.

In addition to accuracy results, response time analyses can provide additional evidence for a serial process model. In the case of size-change and congruent change trials, errors should be the result of the secondary inferential process influencing distance judgments. Considering that these inferences require information from the primary perceptual process, they should be roughly serial in nature. In addition, cue conflicts should increase latencies. This implies that erroneous trials should have additional processing compared to correct trials, and thus have relatively longer response times. Note that this prediction is inconsistent with the results we might expect if participants were merely adopting a speed-accuracy trade-off when generating responses.

When accuracy and response time results are taken together, changes in object size should reduce accuracy and increase response times relative to baseline no-change trials. In addition, the degree of accuracy reduction (or deviation in distance reproduction tasks) and response time evidence can further determine the relative influence of relative and familiar size cues from visual angle in judgments of lateral separation.

Summary

In this introduction I have reviewed the size and distance perception literature to motivate the possible extension of Gogel and Da Silva's (1987b) theory of off-sized perceptions to judgments of lateral separation. Size and distance perception were originally theorized to agree with the SDIH, which states that there is an inverse relationship between perceived size and perceived distance when visual angle remains constant (cf. Equation 1). However, evidence from the moon and Ebbinghaus illusions suggests that the original SDIH inadequately captured size and distance perception. A two-process theory of off-sized perceptions was proposed to account for the size-distance paradox identified in the aforementioned visual illusions. This two-process theory was necessary to account for the evidence from the head-motion task, which found a dissociation between perceived distance (measured by head-motion) and distance judgments (verbal reports of distance). The theory of off-sized perceptions proposes that a primary perceptual process is in accord with the SDIH, while a secondary cognitive process calibrates distance judgments whenever objects are perceived as off-sized (when an expected or perceived size conflicts with a known or familiar size). To date, the only evidence used to support the theory of off-sized perceptions has been egocentric distance judgments.

In the remainder of this thesis I will present four experiments that examine the role of object size in judgments of lateral separation using a change detection methodology. A one-shot change detection task was adapted to Gogel's (1998) optical expansion stimuli to examine the relative contribution of size cues and visual angle on judgments of lateral separation. An advantage of change detection tasks is that they allow for response times to be recorded, which may help dissociate the relative contribution of visual cues in the perception of exocentric distances.

GENERAL METHOD

The experiments used the following procedures for displaying stimuli according to the one-shot change detection task (Cole et al., 2003; Phillips, 1974; Rensink, 2002), except where explicitly noted in the subsequent method sections of the individual experiments.

Materials.

Apparatus. The present research was developed using the VisionEgg 1.1 Toolkit (Straw, Warrant, & O'Carroll, 2006). VisionEgg is a Python-based OpenGL wrapper for drawing geometric shapes, with a timing accuracy +/-0.17 ms on the present hardware. The stimuli were presented on an LG W3452V 24" LCD monitor set at a 1920 x 1200 pixel resolution (52.1 cm x 32.4 cm physical size) and a 60Hz refresh rate. The specified response time of the monitor was 2 ms. The screen brightness was set to 400cd/m^2. The software was implemented on an Athlon 1700+ processor with 1GB RAM and a 128MB RADEON 9700 video card. Responses were recorded using keypad input from a PS2 keyboard or a PS2 three-button mouse, depending on task demands.

The visual information in the experimental room was closely controlled. The room was maintained under a controlled luminance of 387 cd/m^2 with overhead fluorescent lighting diffused through a grating. This luminance controls the contrast between the room and the stimuli presented on the monitor, and falls within the Illuminating Engineering Society of North America (1993) standards for offices and classrooms. The desk and walls of the room were covered with a minimally-reflective black plastic to reduce the contrast and salience of the wall texture (Cuijpers, Kappers, & Koenderink, 2000). Furthermore, this plastic covered the brick patterning and texture of the wall and eliminated those cues as a possible heuristic for determining relative distance. Finally, all computer peripherals were a matted black colour, with lights and logos covered.

To control for accommodation and motion parallax cues (Gogel, 1976), a Richmond Products Inc. HCRFMR floor model chin rest was placed at a fixed height of 100 cm such that the participants' eyes were centered on the monitor at a distance of 60 cm. An adjustable-height office chair was used to fit each participant to the equipment.

Stimuli. In Experiments 1 to 3, the source image consisted of two identical white squares appearing on the central horizontal axis of the computer screen. They were placed at equal distances from the centre of the display. White squares were selected to ensure that the objects had no features which might promote cues other than relative size and familiar size[3] (Gogel, 1998; Gogel, 1965; Gogel & Harker, 1955). The squares' identical sizes also controlled for the perception of the relative depth of the objects as perpendicular to the observer and equidistant (Gogel, 1965; Gogel & Harker, 1955). Moreover, plain shapes are unlikely to cue prior semantic or episodic knowledge, such as prototypical sizes and/or arrangements of objects influencing the perception of scale. Consequently, the squares yielded no implicit or inferable information about depth. In Experiment 4, a single white square was presented. The screen background was set to black to minimize contrast with the edges of the monitor, the colour of the peripherals, and the minimally-reflective black plastic surrounding the monitor.

In order to minimize eye saccades, stimuli were chosen such that the component objects and distances could be viewed in their entirety within the macula, the central

[3] In the following Experiments, "familiar" size refers to a size cue set by a template (i.e., the size of the stimuli in the source image) and not by prior experience.

region of the retina with the highest acuity vision. It subtends an area of approximately 16.7° of the visual field (Haber & Hershenson, 1973). Thus, an image must not subtend more than 16.7° of visual angle if saccades are to be avoided. Although the current methodology does not guarantee that participants did not saccade between the stimuli and other objects in their field of view (e.g., the edge of the monitor or the mouse/keypad), the goal of the task parameters was to limit salience of these objects in an attempt to minimize participants' tendency to make saccades. Additionally, the foveola, the region of the fovea with the most detailed visual acuity within the macula, subtends approximately the central 2° of the visual field. This acuity is reduced by 50% when the viewable object subtends 5° of the visual field. Thus, to maintain the most accurate size judgment, objects should ideally subtend less than 2-3° in the visual field (Irwin, 1992).

The minimal size of the objects presented in this thesis was determined from change detection studies by Vogel, Woodman, and Luck (2001; 2006) who used stimuli sizes of 0.65° x 0.65°. Additionally, in Cole et al. (2003), objects varied in size from 0.90° - 2.8° of the visual field. With the aforementioned sizes and biological constraints in mind, this study was thus conducted with stimuli of 9 different sizes between 0.65° - 2.25° in 0.20° increments. The objects in the source image had three possible sizes (1.05°, 1.45°, & 1.85° for Experiments 1, 2, and 4; size was set to only 1.45° in Experiment 3). The objects' size in the target image either remained the same as in the source image, or was varied in the target image by +/- 0.20° or +/- 0.40°. The decision to change object size in units of visual angle was made to maintain linear size changes in angular size, but at the current range of stimulus sizes, there is a negligible curvature of the visual field. Each 0.20° incremental change in object size (from 0.65° – 2.25°) was equivalent to a change of .21 cm (~8 pixels). Thus, a constant change in angular size (i.e., visual angle) is approximately a constant change in absolute size (i.e., pixels or centimeters).

The initial distance between objects was generated using multiples of initial object size, ranging from 2, 3, or 4 objects apart. Based on the aforementioned sizes of the objects and the distances between objects, the range of possible stimulus sizes (object size and distance) ranged from 2.60° to 13.44°. With the largest stimulus subtending 13.44° of the visual field, all stimuli fall within the approximate 16.7° visual field of the macula. It is also important to note that the critical measure (i.e., the distance between the objects) only occupies 8.98°. Again, the curvature of the visual field had a negligible impact on perceived distance: comparing the angular size of the largest stimulus to the sum of the linear sizes of the objects and their lateral separation would yield a difference of 0.06° (0.05 cm).

The pattern mask consisted of a randomly-generated static white-noise image with a dot-density of 34 dots per square cm. This image served both to mask the previous pattern and to eliminate any retinal afterimage (i.e., iconic memory trace) that could be used as an index for spatial position. The mask was presented for 600 ms in Experiments 1, 2, and 4, and was varied in Experiment 3 (300 ms, 600 ms, 1200 ms, and 2400 ms).

Procedure.

Before entering the experiment room, the participants completed an informed consent, a background questionnaire, and read all task instructions. Upon entering the experiment room, participants sat at the computer and had their chair adjusted such that they were comfortably sitting centered in front of the monitor with their chin comfortably on the chinrest. Participants' eyes were centered 60 cm from the screen at 100 cm height. The participants were then instructed to fixate on the centre of the screen, to minimize head and body movements during the task as much as was comfortably possible, and to blink between trials to maintain eye lubrication.

A trial consisted of two sequentially-presented images separated by a white-noise mask. First, a source image was presented for 1200 ms followed by a 600 ms randomized white-noise mask. Durations for stimuli presentation were derived from a similar one-shot change detection methodology in Cole et al. (2003). To further justify these presentation times, Palmer (1986) argued that the inter-stimulus interval (ISI; the pattern mask in the current methodology) should exceed 200-300 ms to avoid having the perceptual system process the change between images dynamically (i.e., to avoid the change being detected as apparent motion). Rensink (2002) similarly argued that the ISI should exceed 500 ms, but cautioned against lengthy (e.g., more than 2000 ms) delays so that visual memory does not decay (see also Kikuchi, 1987). Presenting the pattern mask for 600 ms means that the participants should not perceive any apparent motion in depth. By corollary, any change in the size of the objects or separation between the objects should not be a cue to changes in perceived depth due to apparent motion. Distance should be specified predominantly by the specific distance tendency and the binocular cues of convergence and accommodation to the physical distance of computer display.

After the white-noise mask a target image was displayed until a participant made a response (see Figure 5). Responses included three-alternative forced-choice distance judgments (i.e., "closer", "same", and "farther"; Experiments 1 & 3), mouse-dragged distance reproduction (to re-create source distance; Experiments 2 & 4), and open-ended distance judgments with the keypad (1-9 objects apart; Experiment 4).

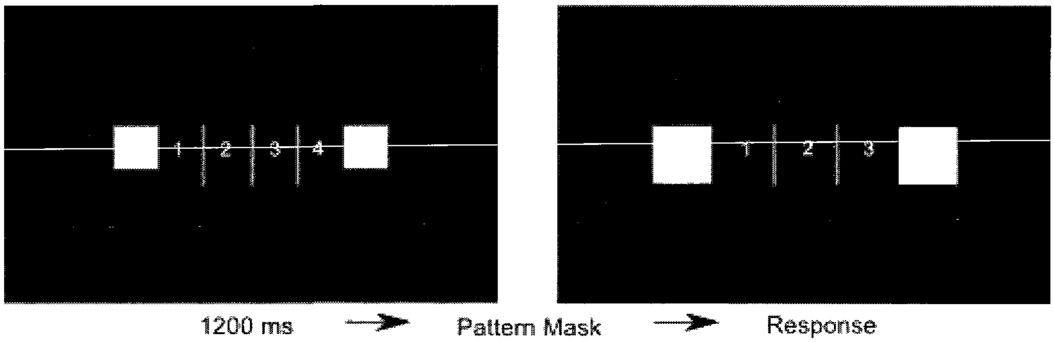

Figure 8. An example of how relative size cue can affect distance perception. Despite the inter-object distance being the same between the source and target images, the relative size of the distance is four objects in the source image and three objects in the target image. The vertical lines and digits did not appear in the experiments and are added here for illustration.

Participants were instructed to respond with their first impression of distance, consistent with apparent task instructions (Epstein, 1963). Participants were further directed to respond as fast as possible without sacrificing accuracy. No feedback was provided regarding the accuracy of their responses. Once a response was made, participants were instructed to press the spacebar to start the next trial. Participants were permitted to take short breaks as needed between trials.

A short four-trial practice phase before each task familiarized participants with the experimental procedures. A second set of practice trials was completed if required to ensure participants understood when to respond. Once the experiment was complete, participants completed different post-test questionnaires. The background and post-test questionnaires did not yield any information that helped better understand the experimental data. Thus, they will not be discussed further.

EXPERIMENT 1

The objective of this experiment was to use a one-shot change detection task to determine the role that object size plays in judgments of lateral separation. Prior research has argued that visual angle is the predominant cue in exocentric distance perception (Haber & Levin, 1993). In other words, when both relative depth and linear separation (i.e., angular size) vary, observers should tend to judge inter-object distance using only the lateral separation between the objects and ignore depth cues. This may be a function of the equidistance tendency.

Gogel and Da Silva's (1987) two-process theory of off-sized perceptions, however, predicts that only the primary perceptual representation should be derived from angular size. The representation generated from the *cognitive* secondary process utilizes top-down information such as familiar size cues to calibrate distance judgments. When an object is perceived as off-sized, this weights the cognitive effects of the secondary process. By independently manipulating familiar size cues (object size) and visual angle (lateral separation), it should be possible to determine if familiar size cues affect judgments of lateral separation in a manner that is consistent with the theory of off-sized perceptions (Gogel, 1998). In particular, changing object size between the source and target images should cause participants to perceive the objects as off-sized, which in turn should more heavily weight the top-down secondary process in the distance judgment. As discussed, this secondary process utilizes familiar size cues in making distance judgments, which would reduce accuracy in the present task.

Participants were asked to detect changes in lateral separation (i.e., changes in visual angle). If visual angle is the predominant determiner of exocentric distance as theorized by Haber and Levin (1993) and Matsushima et al. (2005), then changes in object size should not significantly affect the accuracy of judgments of lateral separation. If, however, the familiar size cue is also a significant determiner of judgments of lateral separation, then changes in object size should reduce the accuracy of inter-object distance judgments consistent with the theory of off-sized perceptions. In particular, in trials where object size changes and inter-object distance remains constant, reduced accuracy compared to baseline trials (where the source and target images are the same) would suggest that there is a cue conflict between visual angle and other (most likely cognitive) cues, such as familiar size or relative size. This cue conflict may also be reflected by relatively higher response times in trials where object size changes compared against baseline trials with no cue conflicts.

In addition to visual angle and familiar size cues, participants may adopt a heuristic using relative size cues to develop an *ad-hoc metric,* that is, participants may use object size to generate a ratio of object size to inter-object distance. For instance, when observers perceive the distance between a car and a building, they may not necessarily make a judgment that the distance is 18 m wide, but instead judge that it would be possible to fit three cars between the car and building (thus generating an ad-hoc metric ratio that the exocentric distance is three cars wide). Using knowledge of the familiar size of a car, it would then be possible to make an accurate distance judgment even without further assessment of the distance. This is because, once an ad-hoc metric is generated, there is no requirement for memory of visual angle or inter-object distance. All that is required is memory of the ratio (e.g., three car-widths) and a familiar size for the object.

A significant number of *stimulus-ratio* errors would further support the proposal that participants are adopting an ad-hoc metrics heuristic as a cue to exocentric distance judgments. Stimulus-ratio errors occur when viewers make three particular errors: 1) when object size is increased in the target image then viewers would judge the objects closer together in the source image (an underestimation error); 2) when object size is decreased in the target image then viewers would judge the objects farther apart in the source image (an overestimation error); and 3) when both object size and distance are varied in proportion (i.e., keeping the ratio the same) then viewers would judge the distance unchanged. When both object size and distance are varied in proportion, the ad-hoc metric ratio (as a relative size cue) conflicts with both visual angle and familiar size cues. A list of cue conflicts for Experiment 1 is presented in Table 1.

Table 1
A Summary of Possible Cue Conflicts in Experiment 1

	Size Unchanged	Size Changed
Distance Unchanged	• No cue conflicts	• Familiar size cue conflicts with visual angle • Ad-hoc metric ratio violated
Distance Changed	• Familiar size cue conflicts with visual angle • Ad-hoc metric ratio violated	• Familiar size and visual angle cues conflict with ad-hoc metrics cue

Response time analyses will further help to distinguish between different processing strategies. Relatively longer response times for correct responses than incorrect responses would be consistent with speed-accuracy tradeoffs. Conversely, relatively longer response times for incorrect responses, and specifically *stimulus-ratio* errors, would be consistent with size cues conflicting with the correct response (ostensibly provided by the primary perceptual process).

Method

Participants. Thirty Carleton University undergraduate students (17 women and 13 men, mean age = 23.1 years) were awarded 1% psychology extra course credit for their participation. All participants exhibited normal or corrected-to-normal vision.

Materials. The experimental stimuli consisted of the sequentially-presented images described in the General Method. Both the source and target images consisted of two squares (the objects) of equal size. They were symmetrically located on both sides of the centre of the screen (see Figure 9). On half of the trials, the objects were arranged horizontally (left and right of the centre of the screen) and on half of the trials they were arranged vertically (above and below the centre of the screen).

In the source image, the objects were one of three possible initial sizes (1.05°, 1.45°, or 1.85°) and they were presented one of three possible initial distances apart (2, 3, or 4 object-multiples). Either the source and target images remained unchanged or one of three possible types of changes occurred in the target image: a change in object-size, a change in inter-object distance, or both a change in object-size and inter-object distance. Each stimulus pair was presented under both vertical and horizontal orientation.

Procedure. On each trial, participants were instructed to indicate whether the distance between the two objects was different in the target image when compared with the source image. They were provided with three possible responses: closer, same, or farther. Participants used a three-button mouse to make their decision. The left button was pressed with the index finger of the right hand to indicate "closer", the middle button was pressed with the middle finger of the right hand to indicate "no change/same", and the right button was pressed with the ring finger of the right hand to indicate "farther".

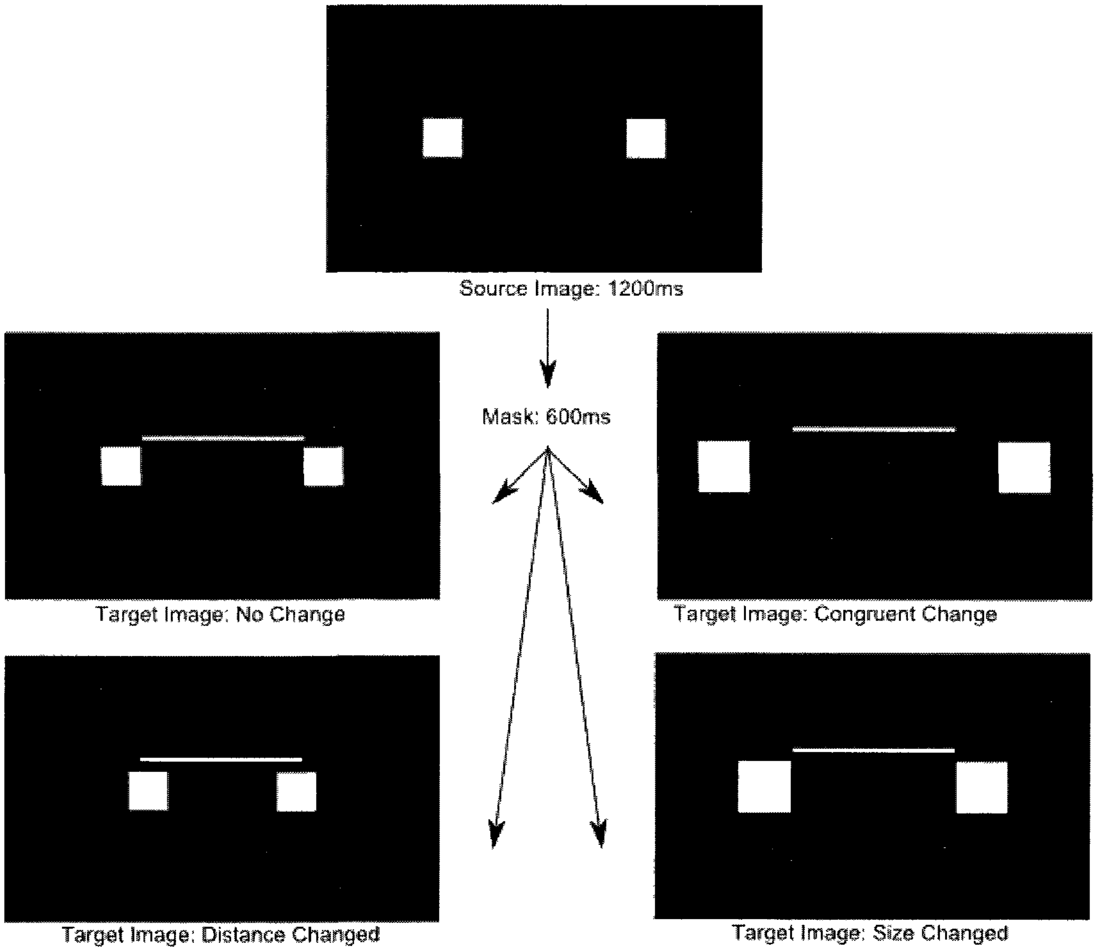

Figure 9. Sample conditions from the one-shot change detection methodology. The bar above the squares in the target images represent the original exocentric distance from the source image. They are included for illustrative purposes and were not shown to the participants.

On each trial, the source image was presented for 1200 ms followed by a white noise mask for 600 ms. Immediately after the mask disappeared, the target image was presented. It remained visible on the screen until participants provided a response, with no cutoff time. Responses times were recorded from the onset of the target image to the mouse-button press. After each response, the experiment software prompted the participants to press the spacebar to continue to the next trial. A break was provided after 108 trials. The total time for the experiment was approximately 25 minutes.

In total, 216 trials were completed during the experimental phase. This included 36 baseline trials where neither size nor distance was changed between the source and target image (i.e., the source and target images were identical). The 180 remaining trials were divided among three change types: 72 in both the size-change and congruent change conditions, and 36 trials in the distance-change condition. The 72 size-change and congruent change trials included an equal number from the three initial sizes (1.05°, 1.45°, 1.85°), three initial distances (2, 3, 4 object-multiples apart), four size-change or congruent changes (increase and decrease by 0.20° and 0.40° of visual angle), and two orientations (horizontal and vertical presentation). There were fewer trials (36) in the distance-change condition because participants exhibited ceiling performance at the +/-0.20° distance change levels in pilot studies and the decision was made to eliminate the +/-0.40° distance change trials from the experiment, cutting the number of trials in half. An error in the randomization algorithm caused several trials from the size-change and no-change trials to always be presented horizontally first. Otherwise, trial order was randomized across participants. The total time for the experiment was approximately 30 minutes.

Results

One participant was excluded from all data analyses because he repeatedly failed to follow task procedures. The remaining 29 participants' results were entered into all subsequent analyses.

Two separate 4 (change type: no-change, size-change, distance-change, congruent change) x 3 (initial distance: 2, 3, or 4 object-multiples) x 2 (orientation: horizontal, vertical) repeated-measures ANOVAs were conducted for accuracy (i.e., proportion correct) and response latencies (in ms). Adopting the analyses of a similar change detection task from Henderson and Hollingworth (2000), data were collapsed across the factor of objects' initial size. Further justification of the removal of initial object size as a factor is that initial distance was specified as a multiple of initial object size. Thus, the two factors are inherently correlated. In the present analyses, 14 responses (of 6048 total trials or 0.23% of all trials) were excluded due to having either no recorded RT or RTs exceeding 10 seconds.

When Mauchley's test of sphericity was violated, Greenhouse-Geisser adjusted values were reported. All *p*s < .001 unless otherwise indicated and all post-hoc analyses are reported with pairwise Bonferroni-adjusted values.

Accuracy. The main effect of change type was significant, $F(1.90, 53.2) = 41.08$, $MSE = 6.67$, $\eta_p^2 = .595$. Participants were most accurate on distance-change trials ($M = .83$), followed by no-change trials ($M = .74$), size-change trials ($M = .61$), and congruent change ($M = .48$; see Appendix A: List of Descriptive Statistics

Table 5 in Appendix A for a complete list of descriptive statistics). Post-hoc comparisons identified that with the exception of the distance-change and no-change conditions ($p = .054$), all other differences between trial types were significantly different (all *p*s < .028). These results support the hypothesis that changing object size between the source and target images (i.e., size-change and congruent-change conditions) causes a cue conflict between size cues and lateral separation, thereby reducing accuracy. Similarly, because there was no change in object size in the distance-change condition, participants' accuracy was not significantly different than in the baseline no-change condition. These results were also consistent with size changes causing participants to perceive the squares as off-sized, which then influenced their judgment of lateral separation.

The main effect of initial distance was also significant, $F(2, 56) = 14.74$, $MSE = .363$, $\eta_p^2 = .345$, with farther distances resulting in reduced accuracy ($M = .70, .67, .62$ for 2, 3, and 4 objects-apart initial distance, respectively). Only the farthest (i.e., 4 objects-apart) initial distance was significantly different from the other two initial distances ($p < .004$). This result is consistent with prior research indicating that accuracy is reduced at farther eccentricities (i.e., larger separation; Levin & Haber, 1993; Matsushima et al., 2005). More relevant to the present analyses, an initial distance x change type interaction was also significant, $F(6, 168) = 19.96$, $MSE = .014$, $\eta_p^2 = .416$. Accuracy decreased with farther distances for three of the change types (no-change, size-change, distance-change), however, accuracy increased for congruent change trials (see Figure 10). This reversal in the congruent change trials may be due to the reduced effectiveness of relative size cues at farther eccentricities, as specified by the adjacency principle (Gogel, 1965b).

In the congruent change type trials, relative size cues indicate that the distance judgment should be "same" because object size and visual angle both change in proportion between the source and target images. For example, in a congruent change trial, the ratio of object size to separation remains unchanged between the source and target images (e.g., 2 objects apart), even though both object size and separation will either increase or decrease (in proportion). This implies that the judgment from relative size cues conflicts with the judgment indicated by visual angle cues. Visual angle cues instead indicate that the response should be "closer" or "farther" because the visual angle has changed. At closer initial distances, the results are consistent with relative size cues more heavily influencing judgments of separation than visual angle. At the farthest 4-object initial distance, however, the effectiveness of the relative size cue is likely reduced, resulting in judgments of separation becoming more accurate. In fact, at the farthest separation, post-hoc tests reveal that only the accuracy of distance-change trials is higher than the accuracy for the congruent and size-change trials.

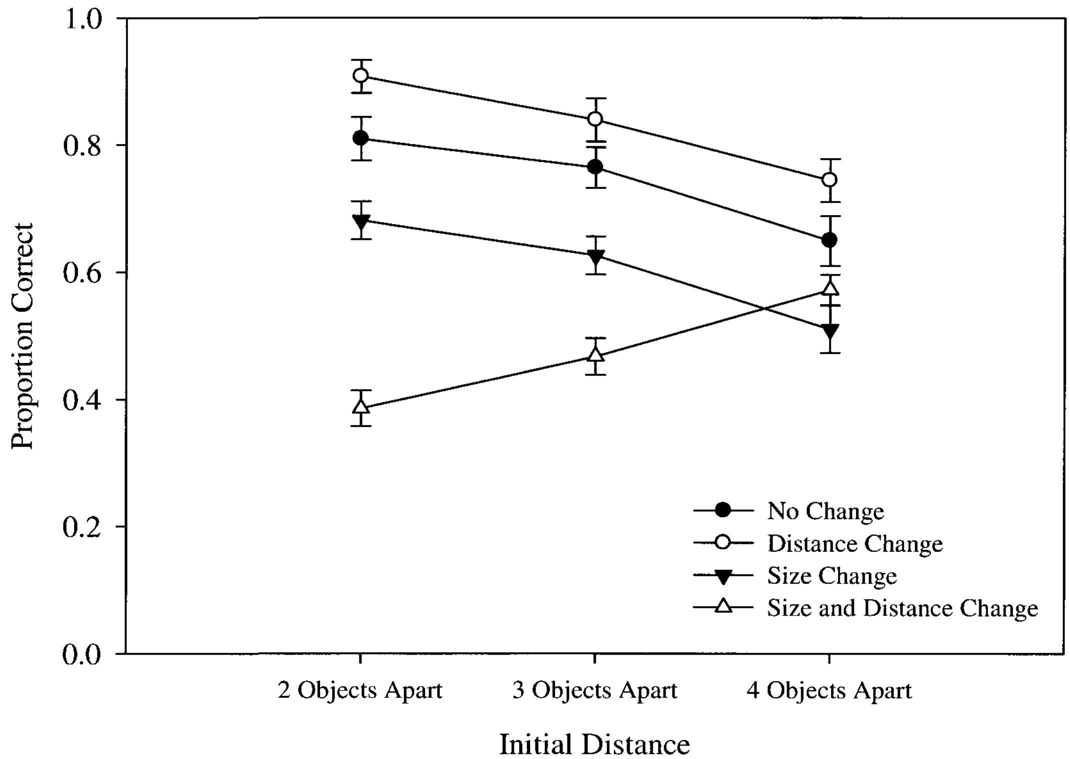

Figure 10. The interaction between initial distance and change type for accuracy. Error bars represent standard error. The reference line represents a chance-level response (33%).

In summary, at 4-objects apart, the effectiveness of relative (and/or perspective) size cues is greatly reduced. Finally, there was no main effect of orientation on accuracy, $F(1, 28) = .406$, $MSE = .012$, $p = .529$, $\eta_p^2 = .014$, nor was orientation present in any significant interaction.

Response Latencies. A histogram of response times is available in Figure 22 (see Appendix A). The main effect of change type was significant, $F(2.46, 69) = 18.21$, $MSE = 2420000$, $\eta_p^2 = .394$, with participants responding faster to no-change or distance-change trials (M = 1255 ms and 1294 ms, respectively) than trials involving size-change or congruent change (M = 1404 ms and 1418 ms, respectively). Post-hoc comparisons identified that the RTs were similar for no-change and distance-change trials ($p = .874$), and also similar for the size-change and congruent change trials ($p = 1$). The difference between the no-change/distance-change trials and the size-change/congruent change trials was significant. These results imply that participants were detecting the change in object size, and potentially, that some additional processing was undertaken consistent with some kind of cue conflict.

A main effect of initial distance was also significant, $F(1.60, 44.9) = 3.748$, $MSE = 257000$, $p = .040$, $\eta_p^2 = .118$, such that participants responded more slowly when initial distances were greater (M = 1288 ms, 1326 ms, 1347 ms for 2, 3, and 4 objects-apart initial distance, respectively). Although this main effect was significant, post-hoc tests identified no additional significant difference in RTs between distances ($ps > .108$). Unlike the accuracy results, there was no significant interaction between change type and initial distance. This implies that different initial distances did not engage separate distance judgment heuristics. Finally, similar to the accuracy results, there was no effect of orientation on RTs, $F(1, 28) = 0$, $MSE = 12.2$, $p = .989$, $\eta_p^2 = .000$.

RTs for Correct vs. Incorrect Responses. In addition to examining overall RTs, a 4 (change type: no-change, size-change, distance-change, congruent change) x 2 (response accuracy: RTs for correct and incorrect response) repeated-measures ANOVA was also conducted to determine if there was evidence for differential processes (e.g., differential effectiveness of processes) for correct versus incorrect responses. The initial size, initial distance, and orientation factors were collapsed to provide sufficient data to eliminate the majority empty cells and focus on the key predictions of the change type factor.

Overall, participants were faster on correct trials than on incorrect trials (M = 1316 ms vs. 1495 ms), $F(1, 28) = 26.32$, $MSE = 1860000$, $\eta_p^2 = .485$. This result was consistent with the assumption that participants were not just displaying a speed-accuracy trade-off heuristic when making separation judgments. A more revealing result emerged from the significant response accuracy x change type interaction, $F(1.99, 55.7) = 9.297$, $MSE = 1230000$, $\eta_p^2 = .249$, shown in Figure 11. Participants responded faster for correct responses (than incorrect ones) in three of the change types (477 ms faster in the no-change trials, 151 ms faster in the distance-change trials, and 191 ms faster in the size-change trials). However, participants responded faster for incorrect responses than correct responses (102 ms faster) in the congruent change condition. Post-hoc comparisons indicate that all four change types (no-change, size-change, distance-change, and congruent change) had RTs either significantly different or approaching significance based on their response accuracy ($p < .001$, $p < .001$, $p = .08$, and $p = .07$ respectively). This reversal in RT latencies in the congruent change trials indicates that participants were not just taking longer to respond when unsure of their response.

Examining only correct trials, there was no increase in RT when distance changed when compared with no-change trials (p = 1). There was, however, a significant increase in RT when size changed. This increase in trials where size changed was consistent with increased processing demands due to a cue conflict. Most interestingly, despite no increase in RT when distance changed, when there is a concurrent size and distance change (the congruent-change trials), RTs are significantly higher than even the trials where only size changed. Thus, it appears that having both size and distance change increased the relative difficulty of the task compared to trials where only size changes, even though trials where only distance changed had no impact on RT.

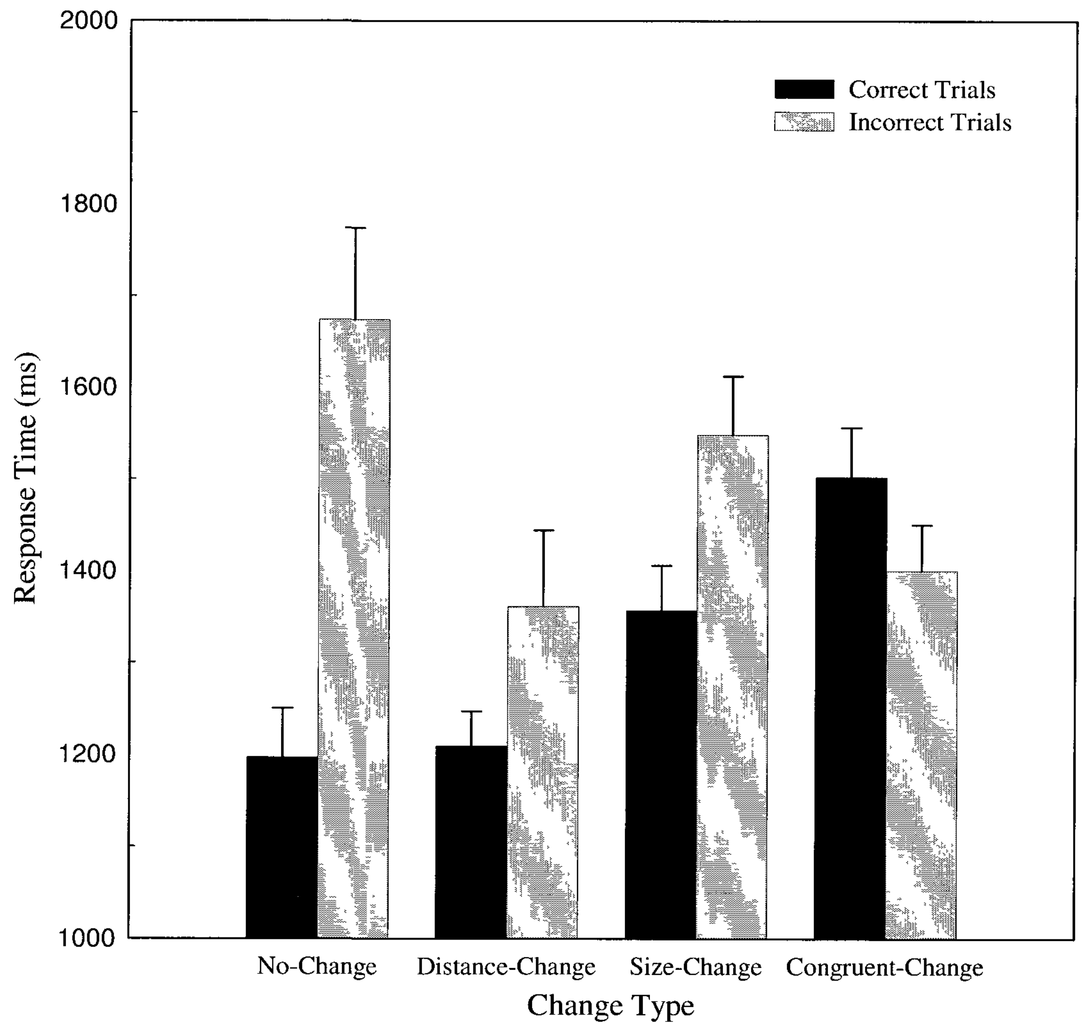

Figure 11. The Interaction between Response Accuracy and Change Type on Response Latencies. Error bars represent Standard Error.

Patterns of Errors.[4] The previous accuracy and RT analyses have identified that object size change trials (i.e., size-change and congruent change trials) have reduced accuracy and increased response times compared to baseline no-change trials. These results, however, do not identify whether the kinds of errors support the hypotheses that off-sized perceptions occur when object size is modified. Responses are judged to be erroneous when participants make an inaccurate judgment of relative separation between the source and target images, that is, when they incorrectly report no change in distance (or the wrong change) when distance was varied, or they incorrectly report a change in distance when distance remained unchanged. In each trial, only one of three possible responses was correct. In examining the patterns of incorrect responses for each change in size and change in distance (see Table 2), the percentage of incorrect responses occurring near-chance levels (50%) would be indicative that incorrect responses did not follow a condition-specific pattern of errors. If, instead, when object size increased participants had more "closer" incorrect responses than in the baseline no-change trials, their responses would be consistent with large off-sized perceptions. Similarly, when

[4] The three-alternative forced-choice distance judgment methodology used in Experiments 1 and 3 excludes the possibility of conducting signal detection analyses (Green & Swets, 1966) because it is impossible to coherently categorize the participants' three choices into hits, false alarms, misses and correct rejections. For example, first consider trials for which the target image is identical to the source image. Here, one could take the decision to classify "same" answers as hits and "different" answers as false alarms. The problem arises when the two other SDT categories are scrutinized. A miss would occur when the source and target images were different, but that the participants answered "same". Unfortunately, this creates a correct rejection category with incoherent set members. Indeed, on a trial for which the squares in the target image were further apart than in the source image, both further apart and closer together answers would be "different". Yet, the closer together answer clearly does not fit in this category as it incorrectly assesses the stimuli. The same problem occurs no matter how one assigns participants answers and stimulus conditions to SDT categories. It follows from this example that the SDT logic may not be applied to the present data set. Nevertheless, I have already argued that the no-change trials constitute a legitimate baseline condition with which other conditions may be compared. Moreover, as this section will show, the three-alternative forced-choice method yields patterns of responses (both correct and incorrect) that were clearly related to the stimulus conditions. These interesting patterns would not have been discovered if a two-alternative forced-choice method had been selected.

object size decreased and participants had more "farther" responses than baseline no-change trials, their responses would be consistent with small off-sized perceptions.

Table 2
Frequency of Response Type in Experiment 1 Examined Across Changes in Size and Distance.

		OBJECT SIZE		
		No Change	**Smaller**	**Larger**
Distance	**Response**			
No Change	CLOSER	68 (25%)	60 (12%)	180 (54%)
	SAME	**772 (Correct)**	**563 (Correct)**	**712 (Correct)**
	FARTHER	202 (75%)	431 (88%)	151 (46%)
	Binomial	$p < .001$	$p < .001$	$p = .061$
Decrease	CLOSER	**415 (Correct)**	**417 (Correct)**	[a]
	SAME	88 (82%)	534 (85%)	
	FARTHER	19 (18%)	93 (15%)	
	Binomial	$p < .001$	$p < .001$	
Increase	CLOSER	16 (23%)	[a]	34 (7%)
	SAME	54 (77%)		435 (93%)
	FARTHER	**451 (Correct)**		**574 (Correct)**
	Binomial	$p < .001$		$p < .001$

Note. Numbers ***bolded*** indicate the number of correct responses. Percent values represent breakdown of response type among only incorrect responses. Exact binomial test assesses proportion of incorrect responses based on 50% chance. Results of binomial test are one-tailed.
[a] In the congruent change trials, size and distance were only changed *in proportion*. Thus, distance could not increase while size decreased, or vice versa.

The results showed that the errors were not randomly distributed. Interestingly, in the baseline no-change trials (where the source and target images were identical), participants were three times as likely (75%) to incorrectly judge a distance farther than closer, despite the fact that neither size nor distance changed. It thus appears that there is some process/heuristic biasing responses towards "farther" judgments. Exact binomial tests further revealed that in the size-change trials, when object size increased there were significantly more incorrect "closer" responses than in the baseline trials. Similarly, when object size decreased there were significantly more incorrect "farther" responses than in the baseline trials. These results are consistent with participants making large and small off-sized judgments, respectively.

In the congruent change trials, the majority of errors were "same" whether or not size increased or decreased. Interestingly, this implies that participants were not solely using the change in object size to assume that, for instance, an increase in object size results in a "closer" distance judgment. Instead, when both size and distance change in proportion, it appears that participants may have been processing both changes in object size and changes in visual angle when making distance judgments. This interpretation is also consistent with the interpretation of the RT results for correct trials, where RTs were increased for size change trials compared to baseline, and even higher for congruent change trials. One possible heuristic consistent with these results is that participants were generating a ratio of object size to inter-object distance, consistent with the *ad-hoc metrics* hypothesis.

Discussion

The results of the present experiment have shown that object size influences judgments of lateral separation. As hypothesized, trials with changes in object size had reduced accuracy compared to baseline trials where size and distance remained unchanged. In trials where object size was increased, participants made more incorrect "closer" judgments, which was consistent with participants making a large off-sized perception. More specifically, when object size is enlarged this increases the relative size of adjacent objects in relation to the separation between the objects. This relative size cue makes the separation between the objects appear relatively closer. Similarly, in trials where object size was decreased, participants made more incorrect "farther" judgments, which was consistent with participants making a small off-sized perception. These size-change results are analogous to judgments in the Ebbinghaus illusion, where the central circle (i.e., analogous to the separation) is perceived relatively smaller (i.e., "closer") when the flanking circles are relatively larger. Supporting this interpretation, McKee and Welch (1992) argue that in judgments of separation, the separation is often judged like an object. Similarly, Lehar (2003) argued that volumes of empty space are perceived with the same metrical properties as volumes of solid objects. One concern regarding the Ebbinghaus illusion analogy as a relative size cue is that, in the illusion, the comparison circles are presented simultaneously. Gogel (1965), however, has demonstrated that relative size cues are similarly effective under both simultaneous and sequential presentation.

In addition to the results of the size-change trials, there was a tendency for participants to incorrectly judge the distance "same" in the congruent change trials. While it is evident that size cues influenced participants' distance judgments, the fact that they exhibited higher accuracy on the size-change trials than the congruent change trials implies that cues are being differentially weighted or otherwise processed. In both cases, object size is similarly varied (thus the "familiar" size cue is constant). The difference is that for the size-change trials visual angle remains constant, while for the congruent change trials, visual angles change in proportion with changes in object size. Changing visual angle did not significantly reduce accuracy in the absence of changes in object size, thus it likely that some heuristic involving both familiar size and visual angle is affecting distance judgments in the congruent change trials.

The *ad-hoc metrics* heuristic is hypothesized to use a relative size cue combining both object size and visual angle to generate an ad-hoc ratio of object size to inter-object distance. In other words, people may use task-specific mental "rulers" with object size as the unit of measure. Because object size is the unit of measure, when object size decreases then this has the effect of compressing the ruler. In the congruent change trials, object size and separation were reduced in proportion. Consequently, the resulting compression or expansion of the ruler was offset by a proportional reduction or increase of the separation between the objects. Consistent with this interpretation, Rock and Ebenholz (1959) found that in reduced cue environments, observers tend to judge the central lines in the two rectangles as equal in length when they fill equal proportions of their frames (see Figure 12).

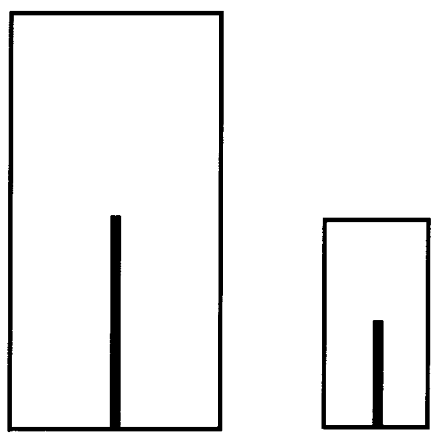

Figure 12. An example of a stimulus from Rock and Ebenholz (1959). When participants are asked to make a judgment of the size of the lines, they judge the lines the same.

It is unlikely that the same-bias on congruent change trials can be attributed to a failure to detect changes because the changes were too subtle for humans to detect. Discussions with participants after the research indicated that size and separation changes were being detected. In addition, the reduction in accuracy in the size-change trials indicated that changes in object size were being detected. Furthermore, prior research has suggested that the changes in object size and distance in the present experiment exceeded perceptual thresholds. McKee and Welch (1992) found that the Weber fraction for detecting changes in object size was 3% - 6% for objects over 0.50°. These results were confirmed by Saunders and Backus (2006) and Aznar-Casanova, Matsushima, Da Silva, and Ribiero-Filho (2008). One difference, however, is that the prior studies used a two-choice forced-alternatives "same-different" task. It is likely that the three responses in the present study would have a higher discrimination threshold, requiring a relatively larger change in size to reach the threshold for detection. At the largest object size (1.85°), the Weber fraction indicates that a change should be detectable with a 0.11° change in size, well below the smallest 0.20° change in the present study. Furthermore, at the smallest object size (1.05°), the discrimination threshold would be a change of 0.07° in object size. In summary, the same-bias in the congruent change trials is not likely due to limitations of the perceptual system.

In the congruent change trials, there are two heuristics which will generate an accurate judgment. The first possibility is that participants initially perceive the visual angle of the separation correctly and then make an accurate judgment based on this initial perception. The second possibility is that participants need to inhibit the incorrect response generated by cue conflict before accurately responding. In the former possibility, RTs should be faster for correct than incorrect responses, while for the latter possibility RTs should be faster for incorrect response than correct responses. Results were consistent with the interpretation that cue conflict needs to be inhibited before an accurate response is generated.

One difference between size-change and congruent-change trials is that in the size-change trials relative size cues bias participants to falsely detect a change in visual angle, while in the congruent change trials relative size cues bias participants to miss detecting a change. It may be that the lower accuracy in the congruent-change trials occurred because the cognitive bias to *miss* the detection of a change (possibly due to an ad-hoc metrics heuristic) was stronger than the tendency to accurately judge the separation based on perceptual cues such as visual angle. In discussions with participants after the experiment, many expressed a feeling that, in these trials, some change had occurred but they could not detect any particular change and thus responded that no change had occurred. This would also explain why RTs are higher for correct responses only in the congruent change trials. In trials with correct responses, participants needed to override their response based on cue conflict (e.g., an ad-hoc relative-size heuristic) to determine the correct response.

In summary, when object size changes participants have an increased tendency to incorrectly judge that distance has changed or miss detecting a change in distance, as evidenced by the reduced accuracy in the size-change and congruent change trials, respectively. These results are consistent with participants judging the object off-sized in the target image. In the current experiment, these off-sized perceptions reduce accuracy and generally increase RTs, consistent with the predictions from the theory of off-sized perceptions.

Another possibility is that participants were automatically (and counter-productively) scaling the target image according to the laws of perspective. Gregory (1963) referred to this phenomenon as inappropriate constancy scaling. While this position would imply that a change in the angular size of the squares was detected (analogous to an off-sized perception), participants could be observing the perceived size of the squares to be the same (i.e., size constancy) and modifying their perception of the objects' perceived egocentric distance instead. When object size increases, this biases the perceptual system to judge that the image is relatively closer in depth. If the separation is perceived to be the same visual angle but relatively nearer to the participant, then according to the SDIH and laws of perspective, the distance must be relatively closer. The reason that accuracy is only marginally reduced during size-change conditions is that any change in depth conflicts with the depth and flatness of the computer screen (Miller, 1999).

There are several reasons to find the perspective account unsatisfactory. First, if one accepts the Ebbinghaus analogy[5] described above, then one should accept that a similar conclusion applies to the Ebbinghaus illusion; namely, that there was a change in perceived size without a concurrent change in perceived depth. Thus, one would not expect a change in perceived depth in the present task. Consistent with this interpretation, no participants self-reported a perceived change in depth despite extensive post-test interviews. In addition, the pattern mask duration was selected to eliminate apparent motion. Thus, changes in size could not be processed as dynamic shifts in depth (what Gogel refers to as optical expansion and contraction in depth; Gogel, 1998). Because the

[5] The analogy is that judgment of the separation between the squares in the present task is analogous to the judgment of the size of the central circle in the Ebbinghaus illusion. Furthermore, the flanking squares in the present task are analogous to the flanking circles in the Ebbinghaus illusion.

stimuli were presented with reduced depth cues (excluding those of the fixed-depth monitor and specific distance tendency), there were no variable depth cues other than the cues provided by changes in object size. Thus, depth was set by the fixed-cues of the actual depth of the monitor in conjunction with the specific distance tendency.

A third alternative to the theory of off-sized perception is that participants were not consistently measuring separation using the inner edges of the squares (as instructed). Instead, participants may have been judging the separation from the centres of the squares (see Figure 13)[6]. This is analogous to the stimulus averaging explanation of the Muller-Lyer illusion (Howe & Purves, 2005). The results of the present experiment are not consistent with this interpretation, however. In the size-change conditions, if participants had been biased to judge separation from the midpoints of the object, then when object-size increased, the separation between the midpoints would have increased. Conversely, when object-size decreased, the separation between the midpoints would have decreased. This implies that participants would have been more likely to judge trials where size increases (both size-change and congruent-change trials) as "farther", and to judge trials where size decreases as "closer". In actuality, when size increased, participants were biased to judge the separation "closer" in size-change trials. Similarly, when size decreased, participants were biased to judge the separation "farther" in size-change trials. In congruent-change trials, participants were biased to judge the separation "same". To summarize, results were opposite to those expected from a stimulus averaging account.

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[6] I thank Rick Gurnsey for making this suggestion (personal communication, January 21, 2011).

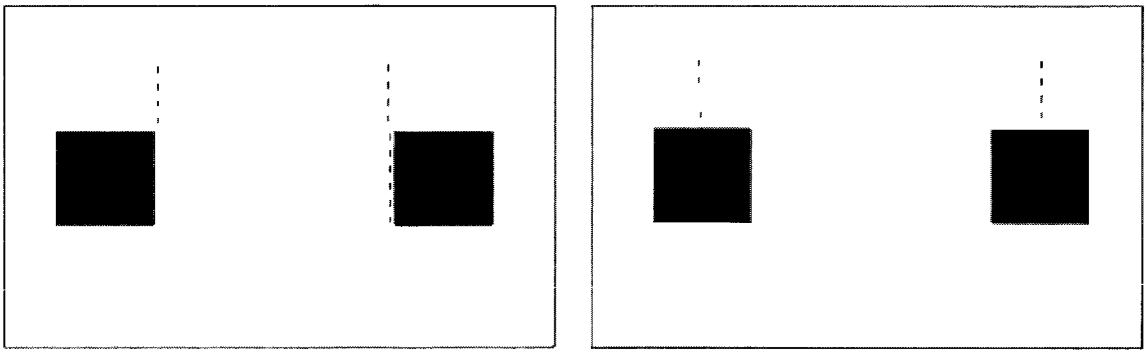

Figure 13. Sample judgments of separation. The dashed line represents the edges of participants' judgment of separation. Participants were instructed to judge distance from the inner edges of the squares (left image). They may, however, have a tendency to judge from the centres of the squares (e.g., from the centre of mass; right image).

Another pattern of results that may, at first glance, be seen as consistent with a stimulus averaging account is that participants responded "farther" three times more often than "closer" in the baseline no-change trials. In the absence of other cue conflicts, if participants were biased towards judging the separation from the midpoints of the objects, then as their focal point of separation shifts from the inner edges of the objects to their midpoints, participants would thus judge the separation farther.

Contrary to the stimulus averaging account, however, participants' tendency to judge the objects "farther" more often than "closer" was only present for the 3-object and 4-object apart initial separation conditions (171 – 33 for "farther" vs. "closer" incorrect judgments). In comparison, at 2-objects apart, baseline incorrect no-change judgments were similarly distributed (31 – 35 for "farther vs. "closer" judgments). Thus, the degree of separation influences the bias to judge separations "farther". Unless participants' propensity to judge separation from the midpoints of the objects was separation-specific, it is unlikely that participants were not following experimental instructions (to judge from the inner edge of the objects).

One possible explanation for the farther-bias being only present at 3-object and 4-object initial separations is that there is an analogous process to the specific distance tendency affecting participants' judgments. Remember that the theorized mechanism for the specific distance tendency is the resting state of accommodation of an observer's retinas. It may be possible that there is an analogous resting state of attention. During the pattern mask presentation, it is possible that the participants' attention slowly shifts towards a central resting state because there is no separation or objects to focus onto. If this return to a resting state feeds back into the perception of distance from the source image, then it would alter judgments such that the relative distances between the source and target images would appear changed. It is important to note the basis for this assumption is dependent upon an ideal resting state between the eyes as opposed to an ideal perceived angle. This is an important distinction because the same separation at a relatively closer depth will correspond to a larger angular size than the same separation at a relatively farther depth.

Coincidentally, the 2-objects initial distance corresponds to the resting state of the eyes (von Hofsten, 1976). The resting state is defined by a segment joining at a right angle the two parallel segments that describe one's gaze stemming from the right and left eye, respectively. It corresponds to the position of the eyes in the absence of visual stimuli. Human inter-ocular distance is about 6 cm from left pupil to right pupil. At a viewing distance of 60 cm from the screen, the inter-object distance at the 2-object initial distance is approximately 5.81 cm. It is possible then, that the resting state of visual attention corresponds with the resting state of the eyes. Under this interpretation, during the pattern mask and in the absence of visual stimuli, the focus of attention is biased towards this resting state. At farther separations, participants' perception of the distance in the source image is compressed as the extent of their focal attention is also compressed. Thus, the separation in the target image is perceived to be relatively farther due to the compression of the separation in the source image.

While the prior interpretation is consistent with the results from the current experiment, there is no direct evidence that any change in attention is occurring during the pattern mask. In fact, despite many studies on the nature of the attentional "spotlight" or "zoom-lens" (e.g., Broadbent, 1982; Erikson & Schultz, 1979; Egeth & Yantis, 1997), few studies have examined how changes in attention influence the memory of prior perceptions. Sagi and Julesz (1985) had participants decide whether two simultaneously presented stimuli were the same or different. The stimuli were situated at different locations on the screen and were followed by a mask. Once the stimuli were masked, participants' ability to accurately discriminate whether the two stimuli were the same or different was independent of their separation on the screen. This result indicated that participants' shifts in attention were not similar to analog movements; that is, that participants' attention did not linearly scan across the screen when shifting between the two stimuli. In addition, Stuart, Bossomaier, and Johnson (1993) have argued that size perception occurs pre-attentively; thus changes in size and separation are processed independently of focal attention. These results are inconsistent with the attentional-feedback hypothesis described above. In Experiment 2 and 3, further investigation will help to determine the nature of the "farther" bias in the no-change trials and determine the likelihood of attentional shifts feeding back into prior memory for object size or separation.

In summary, the results of Experiment 1 identified a strong influence of object size on judgments of lateral separation. These results were consistent with the predictions of the theory of off-sized perceptions, and were not consistent with a stimulus averaging account (e.g., participants judging from the centre of the squares). Furthermore, while the results could also be consistent with the view that participants automatically scaled the image according to the laws of perspective, the evidence to support this perspective was limited. A drawback of the current methodology is that the forced-choice response only provides categorical data, which cannot be used to determine the proportion bias of object size on judgments of separation. To address these questions, Experiment 2 replicated and extended the design of the current study using a distance reproduction response. Instead of responding “closer”, “same”, or “farther”, participants used the mouse to recreate the distance from the source image. This distance reproduction response provided more evidence as to the perception of the quantitative change in distance judgments, which should further clarify the nature of participants’ biases in judgments of lateral separation.

EXPERIMENT 2

The objective of this experiment was to replicate and extend the results of Experiment 1 by requiring participants to respond with a mouse to reproduce the distance from the source image. By requiring participants to recreate their initial distance judgment, a quantitative (i.e., metrical) measure was recorded to examine the influence that changes in object size exhibited on distance judgments. More specifically, increasing object size should bias participants to linearly increase their distance reproductions (overestimation), and decreasing object size should bias them to linearly decrease their distance reproductions (underestimation). If changes in object size do not influence distance reproductions, then dragging accuracy (measured in deviation from expected location) should remain unchanged when object size changes. This lack of influence would support the view that visual angle is the predominant cue for distance perception. If, as seen in Experiment 1, changes in object size do significantly influence the perception (and subsequent reproduction) of distance, then dragging accuracy should change linearly with changes in object size.

Similarly, the theory of off-sized perceptions predicts that changes in object size should more heavily weight size cues (e.g., secondary cognitive processes) resulting in altered distance reproductions. Unlike Experiment 1, where, for example, size increases would result in a bias to report a "closer" response, participants should instead be biased to reproduce the distance farther. This is analogous to the "closer" response from Experiment 1 because participants are calibrating for the original separation appearing closer, then dragging farther to compensate.

Furthermore, the use of the mouse to reproduce distance provides participants with a wider range of visuospatial cues to perform the task than in Experiment 1 because they receive both motor feedback (from the mouse) and visual feedback (from the screen) when reproducing the distances. Hence, it is possible that this additional feedback may mitigate the influence of changes in object size on distance reproductions. It may also be possible that when object size changes, participants' deviation may not follow any predicted pattern. A lack of linear relationship between changes in object size and dragged distance would imply that participants are having difficulty recalling the distance from the source image and are guessing. Under these circumstances, it is likely that the change in object size has either overridden the memory trace of the distance or has made the memory trace otherwise unavailable for comparison. Still, it was expected that Experiment 2 would replicate the central results from Experiment 1: distance would be overestimated when object size was reduced between source and target images, and conversely, distance would be underestimated when object size was increased.

In addition, it was expected that response times would increase linearly with the reproduced distance in the target image, although changes may better fit an inverse log function because most mouse-dragging time is based on its initial acceleration and deceleration to target, and is not based on a constant dragging velocity (McKenzie, 1992). Nevertheless, response time analyses may be less informative than in Experiment 1 because the effect that changes in object size have on response times may be subsumed by variability in the physical mouse-dragging process.

Method

Participants. Twenty-three Carleton University undergraduate students (12 women and 11 men, mean age = 21.0 years) were provided 1% psychology course credit for their participation. All participants exhibited normal or corrected-to-normal vision and were right-handed.

Materials. The experimental stimuli consisted of the sequentially-presented images described in the General Method. In the source image, two squares of equal size (the objects) were presented at an equal distance from the centre of the screen (see Figure 14). In the target image, one square was anchored on the screen and grayed out, representing the fact that it could not be dragged. The other square was adjacent to the first, placed closer to the centre of the screen (in the direction to be dragged by the participant).

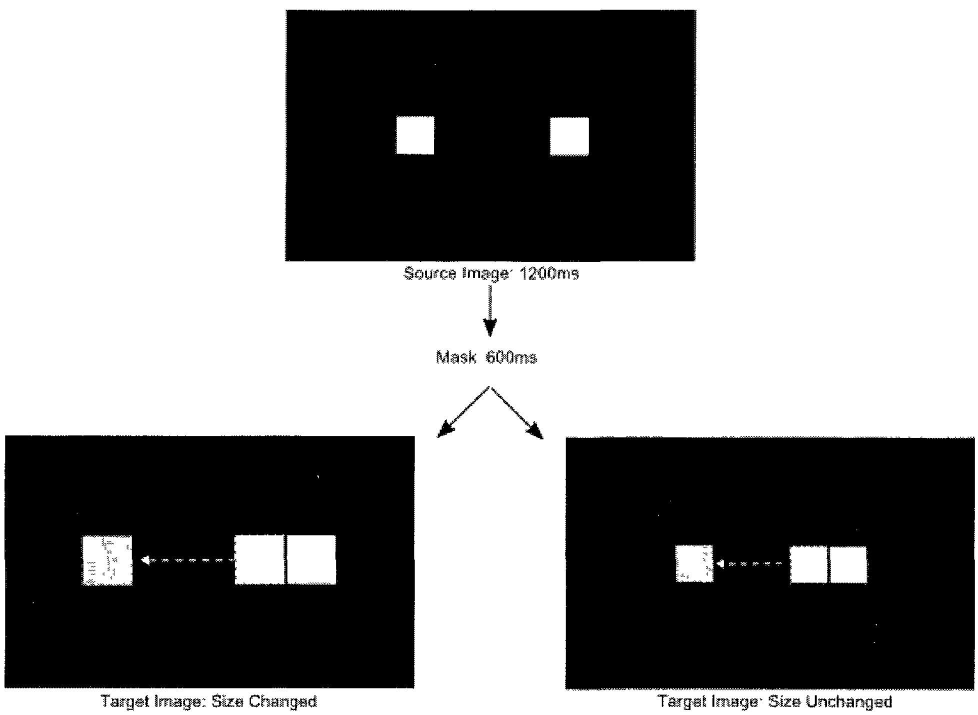

Figure 14. Sample conditions from the distance reproduction methodology. The arrow between the two leftmost squares in the target images represents a participant dragging the square to reproduce the distance from the source image. Only two squares were presented to participants.

The initial object size, initial distance, and orientation were all the same as in Experiment 1. The anchored object was counterbalanced such that on half the trials the anchored object was to the left (in horizontally-presented trials) or above (in vertically-presented trials) the centre of the screen, and on half the trials the anchored object was to the right or below the centre of the screen. Each stimulus pair was presented under both vertical and horizontal orientation, and presented with both the left (or above) and right (or below) object anchored.

Procedure. On each trial, participants were instructed to reproduce the distance from the source image. They held the left mouse-button down while dragging the unanchored object until they believed the distance was accurately reproduced. Once they believed the distance was the same in the target image as recalled from the source image, they released the left mouse-button to set their response. In the trials under horizontal presentation, only horizontal input (left or right motion) from the mouse was processed by the experimental software. Hence, it was impossible to drag the object up or down. Similarly, in the trials under vertical presentation only vertical input (up or down motion) from the mouse was processed. McKenzie (1991) determined that diagonal shifts during dragging increase RTs by up to 3%. It was assumed that that any increase in dragging RTs would be systematic and that they would average out across trials.

On each trial, the source image was presented for 1200 ms followed by a 600 ms white noise mask. Immediately after the mask disappeared, the target image was presented. It remained visible on the screen until participants provided a response with no cutoff time. Response times were recorded from the onset of the target image until mouse-button was released. After each response, the experimental software prompted participants to press the spacebar to continue to the next trial. Participants were instructed to use their left hand to press the spacebar to advance between trials and their right hand to drag the mouse, regardless of their handedness. A break was provided after 90 trials.

In total, 180 trials were completed during the experimental phase. The trials were equally divided among five change types (36 trials per type): size increased by 0.40° of visual angle, size increased by 0.20° of visual angle, size unchanged, size decreased by .20° of visual angle, and size decreased by .40° of visual angle. Each change type included an equal number of trials from the three initial sizes (1.05°, 1.45°, 1.85°), three initial distances (2, 3, 4 object-multiples apart), two orientations (horizontal and vertical presentation), and anchor (left/above and right/below). The total time for the experiment was approximately 20 minutes.

Results

Two separate 5 (size-change: large-size-increase, small-size-increase, no-change, small-size-decrease, large-size-decrease) x 3 (initial distance: 2, 3, or 4 object-multiples) x 2 (orientation: horizontal, vertical) repeated-measures ANOVA were conducted for accuracy (i.e., deviation) and response times (in ms). Deviation was measured as the difference between the dragged distance and the original distance presented in the source image. Deviations for which the objects were too close (underestimation) are represented as negative (-) values, and deviations for which the objects were too far (overestimation) are represented as positive (+) values. Similar to Experiment 1, data were collapsed across the factor of objects' initial size. Data were also collapsed across the factor of object anchor as it was counterbalanced among participants. In the present analyses, 27 (of 4140 total trials, or 0.65% of all trials) were excluded due to having either no recorded RT or dragging deviation more than 3 SD from each participant's mean. When Mauchley's test of sphericity was violated, Greenhouse-Geisser adjusted values were reported. All *p*s < .001 unless otherwise indicated, and all post-hoc analyses are reported with pairwise Bonferroni-adjusted values.

Accuracy. Supporting the hypothesis that object size influences distance judgments, the main effect of size-change type was significant, $F(2.16, 47.6) = 50.95$, $MSE = 11.16$, $\eta_p^2 = .698$. Participants exhibited the least dragging deviation when size did not change (no-change; $M = .05$), followed by small size-change trials (0.20° size-change; $M = -.08$, .19 respectively for size decrease and increase), and large size-change trials (0.40° size-change; $M = -.25$, .27 respectively for size decrease and increase; see Table 4 in Appendix A for a complete list of descriptive statistics). Post-hoc comparisons further identified that the amount of change in object size was reflected in the amount of deviation: small size-change trials were significantly different from both the no-change trials and large size-change trials, with large size-change trials exhibiting the greatest amounts of deviation. Within-subjects contrasts revealed that the changes in object size linearly influenced the accuracy of distance reproduction such that reductions in object size caused distance underestimation and increases in object size caused distance overestimation, $F(1, 22) = 80.34$, $MSE = 23.866$, $\eta_p^2 = .785$. Overall, these results support and extend those from Experiment 1, indicating that changes in size linearly influenced the accuracy of distance judgments. These results were also consistent with the predictions from the theory of off-sized perceptions.

The main effect of initial distance was also significant, $F(1.14, 25.0) = 35.67$, $MSE = 53.26$, $\eta_p^2 = .619$, with farther initial distances resulting in relatively increased amounts of underestimation (M = .40, .04, -.33 for 2, 3, and 4 objects-apart initial distance, respectively; see Figure 15). Post-hoc comparisons identified that the amount of deviation between the three distances were all significantly different from each other. Within-subjects contrasts revealed that different initial distances exhibited linear changes in deviation, $F(1, 22) = 38.08$, $MSE = 60.434$, $\eta_p^2 = .634$. Furthermore, the lack of a significant initial distance x size-change type interaction, $F(5.50, 120.8) = .65$, $MSE = .071$, $p = .676$, implies that any effects of initial distance on accuracy were additive with effects due to changes in object size.

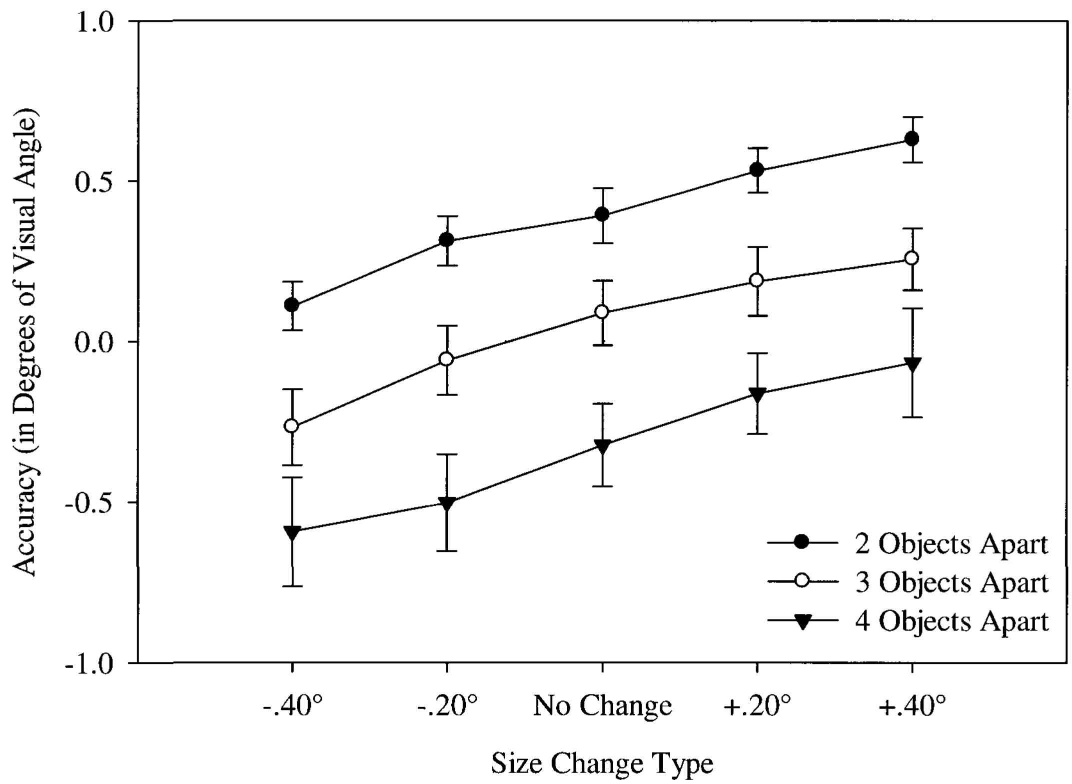

Figure 15. The interaction between initial distance and size-change type on accuracy (deviation). Error bars represent standard error. The dotted line indicates zero deviation.

This underestimation at farther separations is consistent with the "farther" bias (the tendency to incorrectly respond "farther" three times more often than "closer" when the source and target images were the same) seen in Experiment 1. In both experiments, relatively farther initial distances (i.e., separations) resulted in greater underestimation. Unlike Experiment 1, however, this underestimation may have been caused by a directional bias in the method of adjustment using the mouse. For instance, because the mouse was always dragged out from zero distance, there may have been a bias to underestimate distance reproductions. This directional bias, however, does not explain why there was apparent overestimation at the 2 object-multiples initial distance.

While there was no significant main effect of orientation, $F(1, 22) = .24$, $MSE = .19$, $p = .631$, this factor did significantly interact with size-change type, $F(4, 88) = 5.29$, $MSE = .01$, $p = .001$, $\eta_p^2 = .194$. Under both vertical and horizontal presentations, the effect of size changes on deviation was similar. Under horizontal presentation, however, the trend was reduced (i.e., the slope was slightly flatter). This effect was minimal, as post-hoc comparisons identified no significant differences between orientation and change type (ps > .136).

Response Latencies. A histogram of response times is available in Figure 23Figure 22 (see Appendix A). Unlike Experiment 1, there was no main effect of size-change type on RTs, $F(2.77, 60.9) = .118$, $MSE = 50000$, $p = .939$. Neither the small size-change trials (M = 2685 ms and 2695 ms respectively for size decrease and increase) nor large size-change trials (M = 2691 ms and 2664 ms respectively for size decrease and increase) were significantly different from each other or from the no-change trials (M = 2706 ms; $p = 1$ for all comparisons). Two possibilities for this lack of size-change type affecting RTs (compared to Experiment 1) are due to methodological differences: the first is that processing the size-change occurs concurrently with the time it takes to physically drag the objects during distance reproduction. The second possibility is that, in the target image, the location of one of the squares is always displaced compared to the source image. Again, the detection of this displacement may occur concurrently with the processes implicated in the detection of size-changes, subsuming any possible RT latencies.

Similar to Experiment 1 there was a main effect of initial distance on response times, $F(1.13, 24.9) = 10.65$, $MSE = 14800000$, $p = .002$, $\eta_p^2 = .326$. Relatively farther distances generated longer RTs ($M = 2524$ ms, 2643 ms, 2898 ms, for 2, 3, and 4 objects-apart initial distance, respectively). This increase in RT with farther initial distance is consistent with participants taking longer to physically drag farther distances. It is possible, however, that these RTs could be due to participants adopting different processing strategies at different initial distances.

To determine whether the increased RTs are indicative of different processing strategies, physical dragging durations were partialled out using Fitts' Law (Fitts, 1954; MacKenzie, 1991, 1992). Fitts' Law is a psychophysical measure used to identify pointing times using both muscular-skeletal and external pointing devices. It is expressed by the following equation:

$$T = a + b \log_2\left(\frac{D}{W} + 1\right) \qquad (10)$$

where T is the average dragging time, a is the initial offset, b is the resolution of the dragging device, D is the distance from the mouse to the object, and W is the size of the object. Interestingly, the slope for the dragging time in this function is dependent on the ratio between the distance to be scanned and the object size, thus a prediction of this equation is that response times will be similar regardless of distances so long as object size remains in proportion to distance.

The values for *a* (135 ms) and *b* (249 ms) were obtained from McKenzie's (1992) mouse drag-to-target task. It was assumed that the resolution of the mouse was similar in McKenzie's task and the present experiment. McKenzie's task, however, required less precision than the current task: participants dragged an object to an icon on a screen, and a given trial was considered to be accurate if the dragged object landed anywhere on the icon. Responses were thus relatively faster for McKenzie. When the target width was reduced to one pixel in size, similar to an accurate distance reproduction in the current task, Fitts' Law predicted response times were similar to those in the current study (Fitts' predicted M = 1970 ms, 2072 ms, 2152 ms for 2, 3, and 4 objects-apart initial distance, respectively). After partialling out Fitts' predicted response times from participants' actual response times, the main effect of initial distance was no longer significant, $F(1.28, 28.2) = 2.07$, $MSE = 422000$, $p = .138$. Thus, it appears that the increased response time for farther distance was due to the increased physical mouse-dragging duration.

Patterns of Errors. To more easily compare the results of the current experiment with those of Experiment 1, participants' accuracy was converted to categorical closer-, no-change, and farther-responses. This was accomplished by determining 99% confidence intervals for trials where object-size remained unchanged between the source and target images for each participant (analogous to the no-change trials from Experiment 1), and plotting all values below this interval as a "closer" response and values above this interval as a "farther" response. All responses in the present study were equated with those from the size-change condition from Experiment 1. Responses were considered erroneous when they exhibited significant deviation such that the response would be considered a "closer" or "farther" response. As seen in Table 3, this calculation preserves the apparent 3:1 ratio for more "farther" than "closer" judgments in the no-change trials.

Table 3
Frequency of Each Type of Response in Experiment 2 Examined Across Changes in Size.

	OBJECT SIZE		
Response	**No Change**	**Smaller**	**Larger**
CLOSER	155 (27%)	435 (41%)	233 (20%)
SAME	**259 (Correct)**	**586 (Correct)**	**462 (Correct)**
FARTHER	413 (73%)	621 (59%)	949 (80%)
Binomial	$p < .001$	$p < .001$	$p < .001$

Note. Numbers ***bolded*** indicate the number of correct responses. Percent values represent breakdown of response type among only incorrect responses. Exact binomial test assesses proportion of incorrect responses based on 50% chance. Results of binomial test are one-tailed.

In the current experiment, compared with no-change trials, there were significantly more "closer" responses when size decreased and significantly more "farther" responses when size increased. This was the reverse of that seen in Experiment 1, where size increases caused more "closer" responses and size decreases caused more "farther" responses when compared with no-change trials. This reversal was due to the fact that, if one were trying to preserve the distance ratio perceived in the source image, changing the size of the object would require a linear change in distance. Thus when object size decreases, instead of perceiving a pre-fixed distance as farther due to the object-to-distance ratio increasing, one would instead reproduce a relatively closer distance and keep the ratio constant. When compensating for this reversal by switching the results of the "smaller" and "larger" size-change judgments, a z-test for proportions identified that similar proportions of response types were found between Experiment 1 and the current study (z = .472, p = .637 for no-change, z = 1.36, p = .174 for size decrease, and z = 3.60, p = .001 for size increase). This similarity in results implies that the distance reproduction task utilized cognitive processes similar to those used in the forced-choice change detection task.

Discussion.

Combined with the results from Experiment 1, the results of the present experiment support the theory that object size has a significant influence on judgments of lateral separation. When object size was increased, reproduced distance also increased linearly with the amount of increase in object size. Conversely, when object size decreases, reproduced distance was reduced linearly with the amount of decrease in object size. These results are also consistent with participants generating large and small off-sized perceptions when object size increases and decreases, respectively. Dragging deviations in the size-change trials, while exhibiting a linear positive or negative deviation with size increases and decreases respectively, did not elicit a proportional change in distance perception. For instance, to maintain proportion of 2-objects apart, a .20° increase in object size of should be reflected in a distance reproduction with a .40° overestimation relative to baseline reproductions (the no-change trials). In fact, the difference was only a .14° overestimation. These results are also similar to the results seen in studies of egocentric distance perception, where changes in object size (i.e., familiar size cues) only have a partial (and generally small) effect on distance judgments.

This partial influence of object size on distance reproductions implies that changes in object size cause a cue conflict with a more veridical distance representation, and that the resulting distance reproduction is based on some average between the two. Across all size-changes and initial distances, deviations were only 13% - 20% of those expected from familiar size cues. It is possible that, because participants are able to correct their mouse dragging (i.e., the mouse dragging was not just a single ballistic movement), they were able to better mediate the effects of size cues. The present study may then underspecify the role of size cues on judgments of lateral separation. It is apparent, however, that size cues are a present yet weak cue to exocentric distance perception.

To determine whether the dragging deviations were comparable with other dragging tasks, McKenzie (1992) also reported on dragging accuracy (in percent deviation) from a comparable mouse-dragging task. In McKenzie's dragging-task, participants had the mouse cursor placed pseudo-randomly on the screen with a target icon at another screen location. Participants would hold down the left mouse button and drag the mouse cursor to the icon and release the mouse button. Mean dragging deviations ranged from 2.8% - 9.6%. The range of separation participants were required to drag were also similar between McKenzie's tasks and the present study: from 1.2° – 15.8° in McKenzie (1992) as compared with 2.10° – 7.4° in the present study. One task difference was that in McKenzie's methodology, participants could only make a single dragging motion with no adjustment allowed (i.e., a ballistic movement). The present study allowed participants to adjust their responses, which may have resulted in reduced overall deviation, but would also result in significantly increased variance in response times. Similar to McKenzie, the present study exhibited a mean deviation of 2.95% when object size did not change. The dragging deviations in the present experiment were thus similar in proportion to those in similar dragging-to-target tasks.

To better compare the current results with those from Experiment 1, the deviations (i.e., overestimations and underestimations) in distance reproduction were re-coded as "farther" and "closer" judgments using 99% confidence intervals for a "same" judgments, with positive deviations being classified "farther" and negative deviations classified "closer". While the number of errors were much higher in the present study, the proportion of response types were similar to those in Experiment 1, including the bias to report three times as many incorrect judgments "farther" than "closer" when size remained unchanged.

In Experiment 1, it was theorized that this bias may have been due to an attentional feedback: there was a shift in attention to a default state during the pattern mask. In particular, attention would return to a rest state roughly corresponding to the default resting state of the eyes (~3.7° of visual angle in the present experiment). If attention was fixated on a separation less than 3.7°, then as the attentional window shifted out during the pattern mask, this would feed into the representation of the objects' separation from the source image, expanding it. This interpretation assumes that the objects and separation would occupy the same proportion of the attentional "window", thus a shift-out (expansion) would result in a bias to overestimate the separation, and a shift-in (compression) would result in a bias to underestimate the separation. In the present study, this attentional-feedback may have caused a linear change in deviations during distance reproduction, with accurate distance reproduction at 3-objects apart (M = .04° deviation), overestimation at 2-objects apart (M = .40°, a .36° shift), and underestimation (*M* = -.33°, a .37° shift) at 4-objects apart. These results occurred independently of deviations due to object size-changes.

To date, however, little research has examined the role of attentional shifts on visual representations currently held in memory (Yantis, 1998). What is known is that the attentional field of focus can be variably-sized based on task demands, but has a minimum focal region of approximately 1° of visual angle (Eriksen & Hoffman, 1973). In addition, Castiello and Umilta (1990) have shown that the edges of objects can serve as anchors to set the boundaries of focal attention, although these "boundaries" are better defined as a gradient drop-off of attentional resolution. Perhaps more relevant to the present study, Herrmann, Montaser-Kouhsari, Carrasco, and Heeger (2010) found that the attentional field widens when its boundaries fall into regions of spatial uncertainty, that is, when the object size changes as in the present experiment. It is possible, then, that the spatial uncertainty due to changes in object size causes the "farther" tendency. This tendency would be greater at farther separations due to the nature of focal attention: as the boundaries of focal attention expand, the resolution along the boundaries degrades resulting in underestimation. While also consistent with the results of the present study, this attentional widening theory still relies on the assumption that a change in attention feeds back into our representation of the source image.

Another possibility to address the increased degree of underestimation at farther separation may be the method of adjustment in the mouse-dragging response. In the current study, the squares were always presented adjacent to each other in the target image, and participants dragged out one square to reproduce the distance perceived from the source image. Thus the tendency to underestimate relatively farther separations may be a more general feature of the method of adjustment. More specifically, the inter-object distance in the target image is always closer than what was perceived in the source image. This may induce underestimations in distance reproductions, ostensibly through a mental blending of the source and target images. An advantage of this method of adjustment explanation is that it does not require any assumptions regarding the underlying nature of visual attention.

Another non-attention account to address the bias to respond "farther" when object size remained unchanged may be that participants are biased to judge separations from the centre of the objects. While this interpretation was inconsistent with the results from Experiment 1 (it predicted that participants would judge separations "farther" when object size was increased, but instead participants judged separations "closer"), stimulus averaging would explain the patterns of deviation in the present experiment. For instance, when object size increased in the present study, participants reproduced the separation farther. Furthermore, if participants are scaling the separation based on changes in object size, then when object size increased by .20° it would be expected that distances would be reproduced too far by .40°, .60°, and .80° for 2-, 3-, and 4-objects apart initial distance respectively. On the other hand, if participants were biased to judge separation from the midpoints of the objects, then when object size increased by .20°, it would be predicted that the perceived change in separation would be .20° regardless of the separation between the objects. The actual results were a relatively consistent dragging overestimation of M = .14°, .10°, and .16° for 2-, 3-, and 4-objects apart respectively. Relatedly, there is evidence indicating that participants are naturally biased to judge from the centre of stimulus, especially with larger stimulus sizes (Alvarez & Scholl, 2005).

One concern with the stimulus averaging hypothesis was that while it was consistent with the present study; it was not consistent with the patterns from Experiment 1. Furthermore, the theory of off-sized perceptions explains both the patterns of over- and underestimation in Experiment 1 and the results of present study. In Experiment 1, changes in object size caused significantly more incorrect "closer" and "farther" judgments when object size increased and decreased respectively. This is because the relative size of the objects when compared to their separation was changed, analogous to the change in perceived size of the central circles in the Ebbinghaus illusion. In the present study, participants could compensate for their change in perceived separation by altering their distance reproduction. So, when object size increases, instead of judging the same separation "closer", participants reproduce the separation slightly farther to compensate. In addition, due to cue conflict with the relatively veridical perception of separation (theorized to be supplied by the primary perceptual process), there may have been a maximum change in separation that a participant would be willing to reproduce before the change felt too different. Thus, one would still predict a relatively consistent dragging estimation based on different initial separation.

One difference between Experiment 1 and the present one which needs to be addressed is that, in Experiment 1, participants judged the 2-objects apart initial distance most accurately, while in Experiment 2 participants reproduced the 3-objects apart initial distance most accurately. This implies that participants' highest accuracy at closer separations in Experiment 1 was not simply the result of having better visual acuity and attentional resolution at the closest 2-objects apart distance. In the present study, not only were the 3-objects apart separations reproduced most accurately, but the 2-objects separations were overestimated. This overestimation was not predicted by the theory of off-sized perceptions or stimulus averaging, but was consistent with the attentional-feedback hypothesis.

Taken together, the results from Experiments 1 and the present study support the hypothesis that object size influences distance judgments. This influence, however, was only 13% - 20% of predicted values; consistent with prior research on the theory of off-sized perceptions (Gogel & Da Silva, 1987a, b). Specifically, changes in object size affect the accuracy of distance judgments such that increasing object size causes a large off-sized perception resulting in overestimating the separation in the present study, while decreasing object size causes a small off-sized perception resulting in underestimating separation.

To better understand the nature of the theorized attentional-feedback signal, and to determine whether it is possible to dissociate veridical perceptions of separation from the influences of object size, Experiment 3 expands on the forced-choice change detection methodology with the addition of an interference task to increase visual working memory load and by varying pattern mask durations. The interference task should increase the load on cognitive processes, competing for resources with familiar size cues. Casteillo and Umilta (1990) argued that attentional shifts require at least a 500 ms mask to occur. Because the pattern mask in the present study exceeds this value, it should be possible to eliminate any theorized attentional feedback by reducing the mask duration.

EXPERIMENT 3

The objective of this experiment was to replicate and extend the results of the forced-choice change detection task of Experiment 1. As seen in Experiments 1 and 2, changes in object size significantly influenced the judgment and subsequent reproduction of a previously-perceived distance. This influence was most consistent with the predictions of the theory of off-sized perceptions, where increases in object size led to overestimating the separation from the source image, and decreases in object size led to underestimating the separation from the source image. Evidence from the "farther" bias in Experiment 1 – and initial separation in Experiment 2 – indicate that separations less than 3.7° of visual angle were overestimated and separations farther than 3.7° of visual angle were underestimated. This has been theorized to be due to an attentional-feedback signal biased to return to a default position during the pattern mask. This is because there are no objects to maintain a consistent attentional focus during the pattern mask. To determine whether this attentional feedback hypothesis is consistent with prior research on attention, the present study varied pattern mask durations. Casteillo and Umilta (1990) argued that attentional shifts require at least a 500 ms mask to occur, thus reducing the pattern mask duration should eliminate (or greatly reduce) any attentional shift, and increasing the pattern mask duration should exacerbate its effects.

In addition to varying pattern mask durations, the present experiment also included two interference conditions. Their goal was to increase working memory load, which would compete for resources with the theorized secondary cognitive process of the theory of off-sized perceptions. This secondary process uses size and attentional cues to calibrate distance judgments when object size changes. Considering that size cues bias participants to judge distance incorrectly, then by reducing the effectiveness of the secondary process, participants should rely more on veridical visual angle cues from the primary perceptual process. In the present methodology, visual angle cues always designated the correct distance judgment, thus increased accuracy in the interference tasks should provide further evidence for a two-process model. In summary, this two-process model specifies a primary perceptual process largely unaffected by memory and attention demands, and a secondary cognitive process whose effectiveness would be limited by interference tasks.

A methodological concern from Experiment 1 was identified and resolved. In the congruent change trials in Experiment 1, both size and distance always increased or decreased simultaneously. For example, when object size increased (in the size-change and congruent change trials), distance would either remain unchanged (in the size-change trials) or would increase in proportion (congruent change), but distance never decreased. This implies that for any given change in size, only two responses could be correct. For instance, if object size increased then the only correct response would be that distance was unchanged (in size-change) or was farther (in congruent-change). In Experiment 3, additional incongruent-change trials were included where size increases and distance decreases, and vice versa.

These modifications to the methodology entailed novel predictions. Similar to Experiment 1, it was predicted that participants would be biased to incorrectly report that distance was unchanged in the congruent-change trials. In the incongruent-change condition, however, participants should have higher overall accuracy because both perceptual (i.e., visual angle) and cognitive (i.e., familiar and relative size) cues lead to the same conclusion, namely a change in distance. Similarly, RTs should be relatively higher in the size-change and congruent-change trials than the incongruent-change trials. For instance, in an incongruent-change trial where object size increases and distance decreases, both the cue of the ratio of object-size to distance (a relative size cue) and the actual visual angle are decreased, leading to a "closer" judgment. Because both perceptual and cognitive cues facilitate the same judgment, it was likely that RTs in the incongruent-change trials would be relatively faster than the size-change or congruent-change trials. Furthermore, as previously discussed, a shorter pattern mask duration (<500 ms) should eliminate any attentional-feedback bias and a relatively longer pattern mask duration (> 600 ms) should exacerbate the influence of attention. Finally, the inclusion of interference tasks should increase accuracy in the present task due to an increased memory load, limiting the effectiveness of size cues and biasing more veridical perceptual cues such as visual angle.

Method

Participants. Twenty-four Carleton University undergraduate students (10 women and 14 men, mean age = 22.0 years) were provided 1% psychology course credit for their participation. All participants exhibited normal or corrected-to-normal vision.

Materials. The experimental stimuli consisted of the sequentially-presented images described in the General Method and Experiment 1. In each of the source and target images, two squares (the objects) of equal size were presented. In the source image, objects' initial size was 1.45° and they were presented one of three initial distances apart (2, 3, or 4 object-multiples). Either the source and target image remained unchanged or one of four possible types of changes occurred in the target image: changes in object-size, inter-object distance, congruent changes in size and distance, and incongruent changes in size and distance. The size of both objects in the target image increased or decreased by .20°, and distance increased or decreased by a multiple of .20° times the number of objects apart. Each stimulus pair was presented with each of the following pattern mask durations: 300 ms, 600 ms, 1200 ms, and 2400 ms. Unlike Experiment 1, all trials were presented with a horizontal orientation.

In addition to the standard task described above, two interference conditions, based on the methodology of Kosslyn and Holyoak (1982), were performed by the participants: a visual imagery condition where participants had to concurrently rehearse a series of previously-perceived black and white line-art pictures (e.g., a roller skating pig) while performing the task and a phonological condition where participants had to concurrently rehearse four letter word-like consonant-vowel-consonant-vowel CVCV strings (Hilgard, 1951). In total, 12 images and 36 pseudo-words were used. These 48 items are shown in Appendix B.

Procedure. The experiment room setup was identical to that of Experiment 1. On each trial, the source image was presented for 1200 ms followed by a visual white noise mask for either 300 ms, 600 ms, 1200 ms, or 2400 ms. Immediately after the mask disappeared, the target image was presented. It remained visible on the screen until participants provided a response with no cutoff time. Otherwise, the procedure for this task was the same as for Experiment 1: participants were asked to provide a "same", "closer", or "farther" judgment.

A break was provided after each set of 108 trials. In total, 324 trials were completed during the experimental phase, divided among three task types: 108 in each of the standard task, visual imagery dual-task, and phonological dual-task. Each task type was completed in a block of trials. Block order was counterbalanced. The 108 trials per task type consisted of an equal number from the three initial distances (2, 3, 4, object-multiples apart), three object-size changes (no-change, .20° increase, and .20° decrease), three distance changes (no-change, .20° increase, and .20° decrease), and four pattern-mask durations (300 ms, 600 ms, 1200 ms, 2400 ms).

When undergoing the visual imagery interference task, participants were presented with a line-art picture on the screen for five seconds, they were instructed to generate a mental image of this picture, and they were asked to rehearse it while completing several trials of the exocentric distance judgment task. After the five seconds, the screen was cleared and the software instructed participants to press the spacebar to launch the distance judgment trials. After nine experimental trials, the software presented the participants with a question about the image. Participants had to choose from three possible responses. The forced-choice questions regarding the image were presented in the centre of the screen with candidate responses presented below the question in the left-portion of the screen, in the centre-portion of the screen, and in the right-portion of the screen. Participants were instructed to choose the left-most response with the left-mouse button, centre-response with the centre mouse-button, and right-most response with the right mouse button. Once the participants inputted a response, the software presented a new visual image to be rehearsed. Considering that each trial lasted approximately 10 seconds and that 9 trials intervened between the presentation of the line-art and the instructions to answer a question about it, each particular mental image was therefore rehearsed for approximately 90 seconds. The participants did not receive feedback about their performance on this task.

In the phonological interference task, a CVCV string was presented on the screen for 5 seconds. Similar to the visual imagery task, participants were instructed to rehearse the string. After nine trials, three CVCV strings were presented on the screen and participants were instructed to choose the correct response with the mouse. The choices included the same CVCV (i.e., the correct response), a CVCV which rhymed with the correct response, and a CVCV which had the same first letter as the correct response. These confusable CVCVs (which had overlapping phonotactic properties) were used in an attempt to balance the relative difficulty between the visual imagery and phonological dual-tasks. Again, rehearsal lasted approximately for 90 seconds for each CVCV. The total time for the experiment was approximately 35 minutes.

Results

One participant's results were excluded from the analyses because he exercised his right to withdraw from the experiment before its completion. The remaining 23 participants' results were entered into all analyses.

Two separate 3(task type: standard, imagery dual-task, phonological dual-task) x 5 (change type: no-change, size-change, distance-change, congruent-change, incongruent-change) x 4 (initial distance: 2-object, 3-object, 4-object) x 4 (pattern mask: 300 ms, 600 ms, 1200 ms, 2400 ms) repeated-measures ANOVAs were conducted for accuracy (i.e., proportion correct) and response latencies (in ms). In the present analyses, 11 (of 7452 total trials, or 0.015% of all trials) were excluded due to having either no recorded RT or RTs exceeding 10 seconds.

When Mauchley's test of sphericity was violated, Greenhouse-Geisser adjusted values were reported. All *p*s < .001 unless otherwise indicated, and all post-hoc analyses are reported with pairwise Bonferroni-adjusted values.

Accuracy. Similar to Experiment 1, the main effect of change type was significant, $F(1.48, 32.49) = 15.30$, $MSE = 35.27$, $\eta_p^2 = .410$. Participants exhibited higher accuracy on the no-change, distance-change, and incongruent change trials ($M = .64$, .64, and .66 respectively) than the size-change trials ($M = .56$) and congruent-change trials ($M = .36$). Post-hoc comparisons identified that no-change, distance-change and incongruent-change trials had similar accuracy ($p = 1$). Again, similar to Experiment 1, the size-change and congruent-change trials had significantly lower accuracy than the no-change and distance-change trials ($p < .004$). These results further support the hypothesis that changing object size between the source and target images influences participants' judgment of separation. The relatively high accuracy in the incongruent-change trials also indicated that changing object size did not simply reduce accuracy, but only reduced accuracy when size cues conflicted with the cues from perceptual processes.

The main effect of initial distance was also significant, $F(2, 44) = 17.13$, $MSE = 4.15$, $\eta_p^2 = .438$, with farther distances resulting in reduced accuracy ($M = .61$, .59, and .51 for 2-, 3-, and 4-objects apart respectively). Similar to Experiment 1, only the farthest 4-object distance was significantly different from the other two initial distances ($p < .001$). This reduction in accuracy at 4-objects apart initial distance is consistent with both relative size and visual angle having reduced effectiveness at farther separations (Gogel, 1965b; Foley, 1980). This reduction, however, is also consistent with underestimation caused by the theorized attentional feedback signal. For instance, at 4-objects apart the inter-object distance is 5.8° of visual angle, well beyond the approximate 3.7° position of ocular rest. This would cause the attentional field to contract during the pattern mask, resulting in underestimation.

Also similar to Experiment 1, the change type x initial distance interaction was significant, $F(8, 176) = 18.42$, $MSE = 2.58$, $\eta_p^2 = .456$. These results are shown in Figure 16. Accuracy decreased similarly with farther distances for no-change and distance change trials, while the accuracy of congruent-change trials increased with farther distances. This reversal in accuracy in congruent-change trials consistent with the reduced effectiveness of relative size cues at farther distances (Gogel, 1965b). Finally, in the incongruent-change trials there was no difference in accuracy across distances ($p = 1$). When cues from both visual and cognitive cues facilitate a similar response, it is likely that they override the effects of their reduced effectiveness at farther separations.

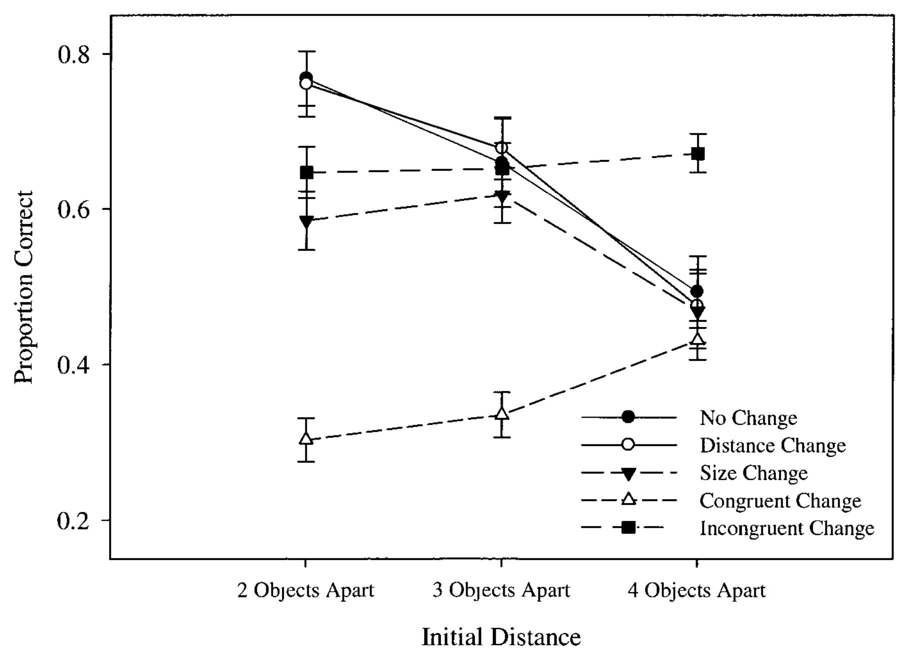

Figure 16. The interaction between initial distance and change type for accuracy. Error bars represent standard error.

A key variable in the present study was pattern mask duration. It yielded a significant main effect, $F(3, 66) = 12.68$, $MSE = 1.40$, $\eta_p^2 = .366$. The results showed that accuracy decreased at longer pattern mask durations ($M = .61, .58, .56, .53$ for 300 ms, 600 ms, 1200 ms, and 2400 ms, respectively). The relative accuracy of the change types behaved differently at longer pattern mask durations, however, as shown by the significant change type x pattern mask interaction, $F(9.87, 32.88) = 6.61$, $MSE = 1.45$, $\eta_p^2 = .231$. Longer pattern mask durations reduced the accuracy of the no-change and distance-change trials ($p < .001$ between 300 ms and 2400 ms) and increased the accuracy of the congruent-change trials ($p < .002$), while the accuracy of the size-change was marginally-higher ($p = .089$) and incongruent-change trials remained unchanged ($p = 1$). For the 2400 ms pattern mask duration, response accuracy was similar across all change types, with the exception that congruent-change trials were significantly different than incongruent-change trials. Thus, it appears that longer pattern mask durations reduced the effectiveness of both perceptual processes (reflected in lower accuracy in distance and no-change trials) and cognitive processes (reflected in higher accuracy in congruent and size-change trials).

A key prediction of the attentional-feedback hypothesis is that the effects of the attentional-shift should not be present at 300 ms mask durations, and would become stronger during longer pattern mask durations (because participants' attention has more time to return to a resting state). Based on the separation between the objects, participants should underestimate the 4-objects apart distances only for 600 ms and greater pattern mask durations. This prediction was supported by the significant pattern mask x initial distance interaction, $F(6, 132) = 2.45$, $MSE = .25$, $p = .028$, $\eta_p^2 = .100$. At the 300 ms mask duration, there was no significant reduction in the accuracy between 3- and 4-object separations consistent with underestimation, $p < .091$. At the 1200 ms and 2400 ms mask durations, there were significant reductions in the accuracy between 3- and 4-object separations, $p < .001$ and $p < .008$ respectively. Interestingly, this reduced accuracy was only seen for the 4-objects apart initial distance. This may be due to the fact that the 2-objects and 4-objects separations differed with regards to their relation to the distance specified by a resting state. The separation was 2.9° for 2-objects apart and 5.8° for 4-objects apart, while the theorized resting state of attention would be similar to that of the position specified by ocular rest, which is ~3.7°. Thus, the difference was only .8° for 2-objects apart, but was 2.1° for 4-objects apart. A further examination of the theorized attentional feedback hypothesis will be presented in the patterns of errors analyses.

Finally, the interaction between change type, pattern mask duration, and initial distance was not significant, $F(24, 528) = 1.30$, $MSE = .116$, $p = .157$, $\eta_p^2 = .056$. It appeared that the drop in accuracy at longer mask durations and 4-object separation did not differentially influence participants' accuracy at different change types. It thus appears that the reduction in accuracy due to pattern mask duration and initial separation was different from any reduction in accuracy due to size cues.

Surprisingly, there was no main effect of interference task type, $F(2, 44) = .89$, $MSE = .14$, $p = .418$, $\eta_p^2 = .039$. Moreover, this finding was not due to participants' inability to recall the interference stimuli. The proportion of correct recall was .87 for the visual stimuli and .97 for the CVCVs. Nonetheless, there was evidence that the interference tasks did reduce the effectiveness of secondary inferential process, as seen by the marginally significant task type x pattern mask duration x initial distance interaction, $F(12, 264) = 1.748$, $MSE = .16$, $p = .057$, $\eta_p^2 = .074$. As seen in Figure 17, accuracy was relatively higher for both of the interference tasks compared to the standard task at only the 300 ms pattern mask duration, and only for the 3- and 4-objects apart initial distance. This result was reflected in the significant interference task x pattern mask duration interaction, $F(6, 132) = 2.20$, $MSE = .23$, $p = .047$, $\eta_p^2 = .091$. Post-hoc analyses identified a trend for the interference tasks to have a higher accuracy than the standard task at the 300 ms pattern mask duration (*ps* < .106; $M = .58$ for the standard task, $M = .62$ for the imagery interference task, and $M = .64$ for the pseudo-word interference task). The interference task x initial distance interaction, however, was not significant, $F(4, 88) = 1.24$, $MSE = .151$, $p = .301$, $\eta_p^2 = .053$. It is likely that at the 2-objects apart initial distance relative size cues were the most effective cues to distance judgment, consistent with the adjacency principle (Gogel, 1965a)

In summary, the results of the marginally-significant three-way task type x pattern mask duration x initial distance interaction imply that the interference task had the predicted effect of increasing accuracy in the judgment task. Thus, there was only limited evidence for dissociation between perceptual and cognitive processes consistent with the predictions from the theory of off-sized perceptions. It further appears that longer pattern mask durations subsumed this result. Finally, the 4-way interaction between task type, change type, pattern mask duration, and initial distance was not significant, $F(48, 1056) = 1.07$, $MSE = .107$, $p = .349$, $\eta_p^2 = .046$, nor were the 3-way interactions involving change type ($p > .157$).

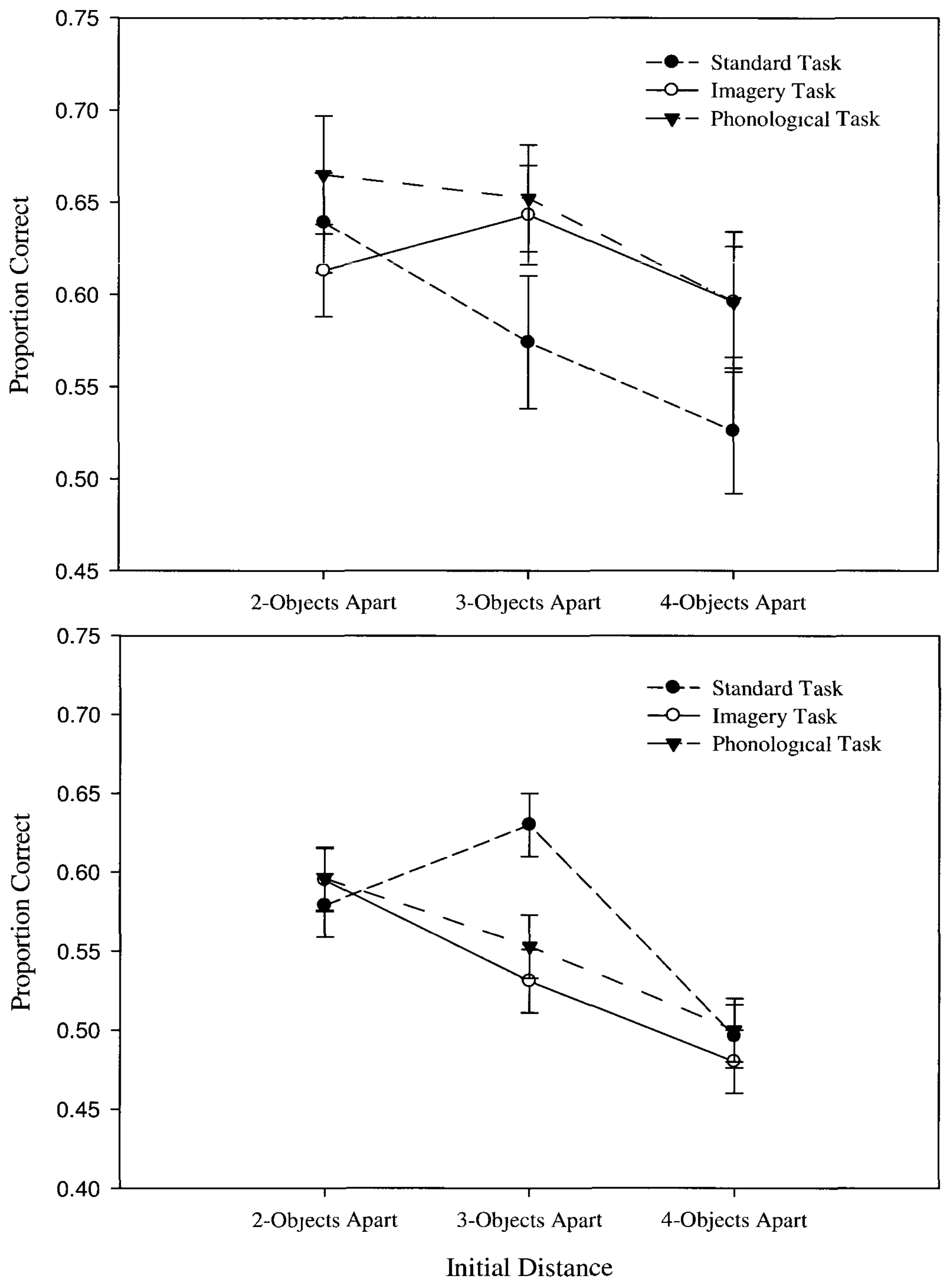

Figure 17. The interaction between task type, initial distance, and pattern mask duration. The top panel shows results at the 300 ms mask duration. The bottom panel shows mean results of 600 ms, 1200 ms, and 2400 ms mask durations. Error bars represent standard error.

Response Latencies. A histogram of response times is available in Figure 24 (see Appendix A). The response time results were similar to those of Experiment 1. The main effect of change type was significant, $F(3.08, 67.86) = 4.12$, $MSE = 1590000$, $p = .009$, $\eta_p^2 = .158$. Participants responded slower in the size-change and congruent-change trials (M = 1227 ms and 1265 ms, respectively) than the no-change, distance-change, and incongruent-change trials (M = 1187 ms, 1178 ms, and 1177 ms, respectively). Post-hoc comparisons, however, indicated that RTs for only the no-change and distance-change trials were significantly different from the congruent-change trials ($p < .012$). The incongruent-change trials were only marginally different than the congruent-change trials ($p = .076$).

Also similar to Experiment 1 was the main effect of initial distance, $F(1.68, 36.98) = 5.72$, $MSE = 3130000$, $p = .010$, $\eta_p^2 = .206$. Post-hoc tests revealed that participants responded faster for the 2-objects apart initial distance trials (1158 ms) than the 3- and 4-objects apart trials (1241 ms, 1223 ms, respectively), $p < .039$. Unlike the accuracy analyses, there was no significant interaction between change type and initial distance. Similar to the accuracy analyses, there was a significant effect of pattern mask duration on RTs, $F(23, 66) = 2.89$, $MSE = 1890000$, $p = .042$, $\eta_p^2 = .116$. Post-hoc comparisons determined that the only significant difference was between the response times for the 600 ms and 2400 ms pattern mask durations (1151 ms and 1251 ms, respectively, $p < .046$).

Also similar to the accuracy results, there was no main effect of interference task. There was, however, an interference task x initial distance interaction, $F(2.36, 51.91) = 4.18$, $MSE = 2360000$, $p = .016$, $\eta_p^2 = .160$. Post-hoc tests revealed that only the smallest

2-object initial distance was responded to relatively faster, and only during the standard task (i.e., no interference task present), $p < .003$. Finally, there was no significant 4-way interaction between initial distance, change type, pattern mask duration, and task type, nor were any other interactions significant ($p > .129$).

RTs for Correct vs. Incorrect Responses. In addition to examining overall RTs, a 5 (change type: no-change, size-change, distance-change, congruent change) x 3 (initial distance: 2-, 3-, 4-objects apart) x 2 (response accuracy: RTs for correct and incorrect responses) repeated-measures ANOVA was also conducted to determine if there was evidence for differential processes adopted for correct versus incorrect responses. The interference task and pattern mask durations factors were collapsed after initial analyses determined no significant effects or interactions, and to provide sufficient data to eliminate the majority of empty cells. Empty cells were due to participants exhibiting ceiling and floor performance in some conditions (thus having no comparative incorrect or correct responses, respectively). The remaining missing values (8 of 713) were replaced by assuming additivity.

Similar to Experiment 1, participants were overall faster on correct trials than on incorrect trials (M = 1186 ms vs. 1331 ms), $F(1, 22) = 24.20$, $MSE = 3650000$, $\eta_p^2 = .524$. Again, this indicates that participants were not simply displaying a speed-accuracy tradeoff. More specifically, participants responded faster for correct responses in the no-change, distance-change, and incongruent-change trials (ps < .03), but not for the size-change and congruent-change trials (ps > .171) as reflected in a response accuracy x change type interaction (shown in Figure 18), $F(1.98, 43.58) = 4.08$, $MSE = 901000$, $p <$.

013, η_p^2 = .157. When there was cue conflict (i.e., size cues conflicting with the separation angle), RTs were relatively increased.

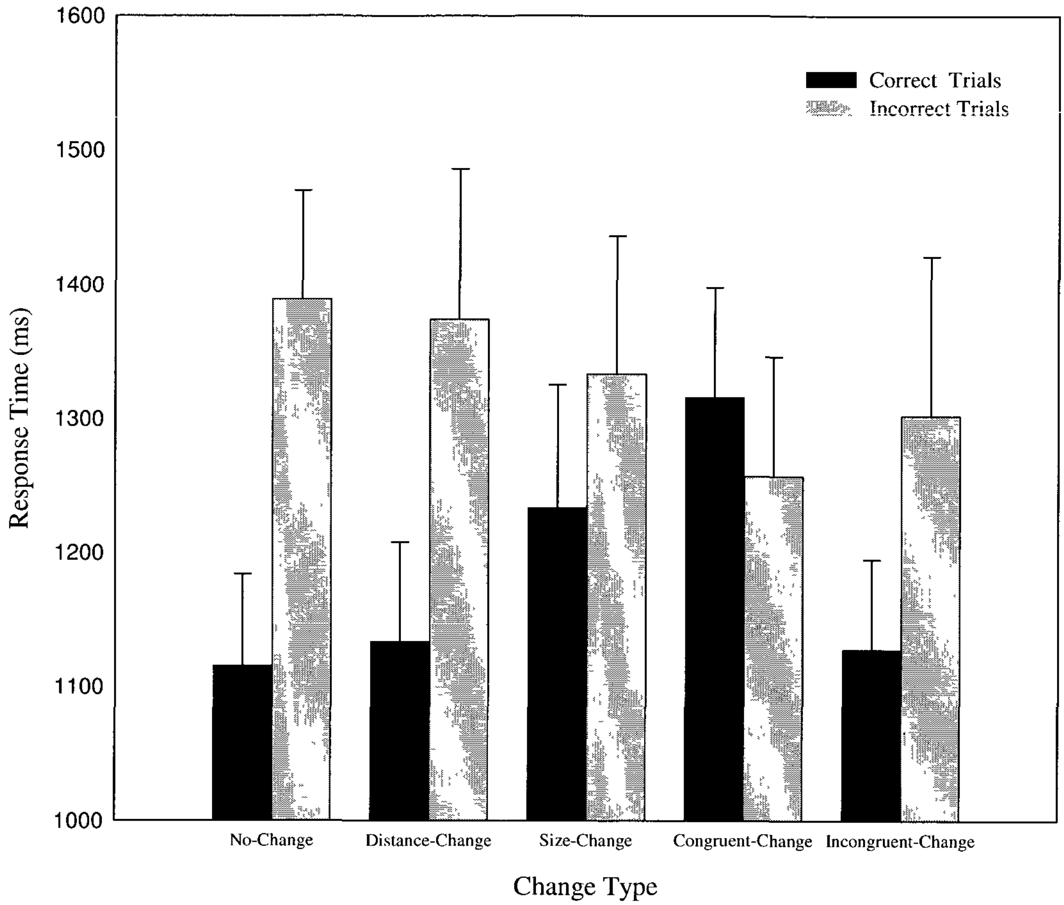

Figure 18. The interaction between response accuracy and change type on response latencies. Error bars represent standard error.

Interestingly, there was also a 3-way response accuracy x change type x initial distance interaction, $F(4.75, 104.52) = 2.59$, $MSE = 404000$, $p < .032$, $\eta_p^2 = .105$. Supporting the notion that the strength of relative size cues is affected by inter-object distance (cf. the adjacency principle), this interaction was caused by relatively decreased RTs for incorrect congruent-change trials at farther distances. In fact, the higher RTs for correct judgments in the congruent-change trials was only significant at the 2-object initial distance ($p = .001$).

Patterns of Errors. Responses were considered erroneous when participants made an inaccurate inter-object distance judgment. This could occur in one of two ways: when they incorrectly reported no change in distance (or the wrong change) when distance was varied, or they incorrectly reported a change in distance when distance remained unchanged. In each trial, only one of three possible responses was correct. The descriptive statistics for the patterns of errors are given in Table 4. The design of Experiment 3 allows for the examination of the data for two cells that were not available in Experiment 1: a condition where distance increased and object-size decreased, and conversely, where distance decreased and object-size increased.

Similar to Experiments 1 and 2, participants were almost three times as likely to incorrectly judge a distance "farther" than "closer" in baseline trials where neither object-size nor distance changed. Also similar to Experiments 1 and 2, in size-change trials, when object size increases there are significantly more "closer" incorrect responses than on baseline no-change trials. Conversely, when object size decreases significantly more incorrect responses are "farther" than baseline. These results are consistent with participants generating large and small off-sized perceptions when object size changes. Furthermore, when cues from object size and distance conflicted (i.e., congruent-change trials), participants tended to report more "same" judgments than at baseline. Finally, when cues from object and size distance facilitated the same distance judgments (i.e., incongruent-change trials), participants exhibited a much higher accuracy overall and an even higher proportion of incorrect "same" judgments. When participants were incorrectly detecting a change, it is most likely that they would respond with the nearest incorrect response (i.e., "same" is relatively nearer response than "closer" for an incorrectly perceived farther distance).

Table 4
Frequency of Response Type in Experiment 3 Examined Across Changes in Size and Distance.

		OBJECT SIZE		
		No Change	**Smaller**	**Larger**
Distance	**Response**			
No Change	CLOSER	86 (29%)	58 (14%)	181 (57%)
	SAME	**530 (Correct)**	**414 (Correct)**	**506 (Correct)**
	FARTHER	212 (71%)	355 (86%)	138 (43%)
	Binomial	$p < .001$	$p < .001$	$p = .009$
Decrease	CLOSER	**518 (Correct)**	**208 (Correct)**	**455 (Correct)**
	SAME	221 (72%)	502 (81%)	335 (90%)
	FARTHER	89 (28%)	118 (19%)	37 (10%)
	Binomial	$p < .001$	$p < .001$	$p < .001$
Increase	CLOSER	83 (29%)	20 (10%)	70 (16%)
	SAME	208 (71%)	174 (90%)	376 (84%)
	FARTHER	**536 (Correct)**	**630 (Correct)**	**382 (Correct)**
	Binomial	$p < .001$	$p < .001$	$p < .001$

Note. Numbers ***bolded*** indicate the number of correct responses. Percent values represent breakdown of response type among only incorrect responses. Exact binomial test assesses proportion of incorrect responses based on 50% chance. Results of binomial test are one-tailed.

The novel prediction in the present study was whether this "farther" bias occurred at the 300 ms pattern mask duration. According to the attentional feedback hypothesis, a 300 ms pattern mask should be insufficient to bias participants to shift their attention (Casteillo & Umilta, 1990). The results were inconsistent with the attentional feedback hypothesis: even at the 300 ms pattern mask duration participants were still twice as likely to judge the separation "farther" than "closer" when object size and distance remained unchanged (34 incorrect "farther" judgments to 15 incorrect "closer" judgments). This "farther" bias, however, was exacerbated by longer mask durations, with 109 incorrect "farther" judgments to 35 incorrect "closer" judgments for the 600 ms and 1200 ms pattern mask durations. It must be concluded then, that there is insufficient evidence to support an attentional feedback hypothesis. If any sort of feedback does occur, this effect in only marginal.

In summary, evidence from the patterns of responses has replicated the findings from Experiment 1, identifying that participants are biased to judge an object "closer" when object size is increased and "farther" when object size is decreased. These results are consistent with the predictions from the theory of off-sized perceptions.

Discussion

The present experiment not only replicated the results from Experiment 1 and 2, but also provided additional evidence about the nature of size and distance perception. As hypothesized, changes in object size influenced judgments of separation such that increases in object size caused relative underestimation and decreases in object size caused relative overestimation. These results were consistent with the predictions of the theory of off-sized perceptions. Furthermore, there was some evidence that a concurrent memory task interfered with the theorized secondary cognitive process. This was reflected by marginally-increased accuracy during the visual interference task, which should have reduced the influence of familiar size cues. The resulting distance judgment would thus be more heavily weighted to relatively veridical perceptual cues such as visual angle.

The theorized attentional feedback hypothesis was not supported by the evidence from Experiment 3. It was theorized that in the absence of cues to anchor the boundaries of participants' attention, this signal would shift towards a default or neutral resting state during the pattern mask. This would have caused overestimation of relatively closer distances and underestimation of relatively farther distances. While there was evidence that longer mask durations exacerbated underestimation of relatively farther distances, the results were inconsistent with the prediction that the 300 ms mask duration would eliminate any attentional shift (Casteillo & Umilta, 1990).

The current experiment introduced a new condition: the incongruent-change, where size and distance are changed in opposite directions. This condition was contrasted with the congruent-change trials, where size and distance changed in proportion. Participants responded more rapidly and accurately in the incongruent-change trials than the congruent-change trials. One reason why participants responded faster and more accurately on the incongruent-change trials was that both the visual angle and relative size cues facilitated the correct distance judgment, which not only improved accuracy but also reduced RTs. More specifically, because there was no cue conflict (and in fact cue facilitation), the threshold to generate a response may have been reached more quickly. In general, longer mask durations increased response times and reduced accuracy. This result is consistent with the hypothesis that the visual memory trace (i.e., angular size of the separation) of the source image was degrading over time, and thus, was reducing participants' accuracy at longer durations. Pattern mask duration, however, interacted with change type. In the case of the size-change and congruent-change trials, accuracy was already relatively lower at the 300 – 600 ms mask durations because of conflicting size cues. These size cues should have also degraded at longer mask durations and should have in fact increased accuracy. Thus, any reduction in accuracy due to a general decay of the visual memory trace was more than offset by the decay of relative size cues. For the incongruent-change trials, because both perceptual and size cues facilitated the accurate detection of a change, this cue facilitation maintained the overall accuracy of trials despite the increased duration of the pattern mask.

In fact, with a pattern mask duration of 2400 ms, post-hoc tests revealed that accuracy was similar between the no-change, distance-change, size-change, and congruent-change trials, $p = .404$. It thus appears that without the cue facilitation from the incongruent-change condition, visual information had degraded to the point that familiar and relative size cues were ineffective with a 2400 ms mask. This is consistent with the results from prior research on visual short-term memory, which can only retain unrehearsed material for at most 2000 ms (Vogel, Woodman & Luck, 2006).

The most surprising result was that participants were able to perform the interference task with only a marginal effect on accuracy. Nevertheless, the interference task appeared to inhibit the processing of familiar size cues under limited conditions, increasing accuracy in the present task. Makovski, Shim, and Jiang (2006) also found a similar marginal effect when using an imagery interference task. These results provide weak evidence that cognitive cues can be dissociated from more veridical perceptual representations of separation generated from angular size. In future studies, visual interference stimuli that are more similar to the lateral separation judgment task stimuli should be selected and the number of trials between interference image and probe should be reduced or at least randomized (Makovski & Jiang, 2008).

There was a difference between the size-change trials between Experiment 1 and present experiment. In Experiment 1, accuracy was highest at 2-objects apart initial distance, and monotonically decreased at farther distances. In the present experiment accuracy was similar between 2-objects and 3-objects separation, only decreasing at 4-objects separation. This difference in the size-change trials between experiments may be due to the fact that only the smaller .20° size-changes were used in the present study. This choice may have influenced participants' judgments relatively more than the .40° size-changes. This is because the squares were closer in size (i.e., more similar) in the .20° changes. Similar to the limited dragging deviations from Experiment 2, it is likely that size cues would be more effective when most similar to the size in the source image. In other words, there may only be a maximal threshold of size difference before an individual perceives the squares as too different to be the same or similar object. Thus, in the present study, the relatively higher effectiveness of the familiar size cue reduced participants' accuracy at the 2-object separation compared to Experiment 1.

Finally, similar to Experiment 1 there was a strong bias to incorrectly judge the separation "same" when size and distance changed in proportion (i.e., the congruent-change trials). In Experiment 1, this was attributed to an ad-hoc heuristic where participants rapidly generated a ratio of object size to separation (like a ruler) and judged the comparative ratios between the images. In order for this theory to be consistent with the evidence from the first three experiments, separation must be judged distinctly from the relative binocular retinal disparity of each stimulus (i.e., no direct comparisons of angular size). Richards (2009) argued that disparity processing cannot be hardwired for distance perception as, at different depths, similar angular disparity (i.e., visual angle) corresponds to different increments of distance. While retinal disparity cannot be used to derive absolute distance judgments, it is possible that changes in angular size can be used to generate relative distance judgments, especially when these judgments occur at a similar depth. If separation and perceived size are processed similarly and viewed concurrently, then the relative retinal disparity (cf. activation) of perceived size and separation can be readily processed as a ratio of relative activations. This ratio of relative activations is the justification for an ad-hoc heuristic. The effectiveness of this theorized ad-hoc metrics heuristic will be further examined in Experiment 4.

In summary, the present experiment has replicated the results from Experiment 1 and 2, showing a significant influence of object size on judgments of lateral separation. In addition, the present study has also confirmed that object size's influence is consistent with the predictions of the theory of off-sized perceptions, and inconsistent with the position that visual angle is the predominant determiner of exocentric distance judgments. Longer pattern mask durations exacerbated the bias to incorrectly judge separations "farther" more often than closer when object size remained unchanged. The results of the 300 ms pattern mask duration, however, were inconsistent with the theorized attentional feedback hypothesis. Furthermore, the visual interference task provided evidence that the influence of size cues can be dissociated from more veridical perceptual cues, although this effect was only marginal in the present study.

While Experiments 1 to 3 focused solely on judgments of lateral separation, one of the key hypotheses in extending the theory of off-sized perceptions to exocentric distance judgments is that perceived size and separation engage the same perceptual mechanisms. For instance, using the stimuli of Experiments 1 and 3 as an example, the theory of off-sized perceptions predicts that perceiving the width of either square employs the same perceptual resources as perceiving the separation between the squares. To investigate whether lateral separation and perceived size are processed similarly, Experiment 4 examined whether changes in object size affect line magnitude estimates and line productions (i.e., size judgments). In addition, Experiment 4 examined the effectiveness of participants using an object as an ad-hoc mental ruler by having participants estimate (and produce) lines using "square lengths" as a metric.

EXPERIMENT 4

Experiment 1 and 3 explored participants' judgments of lateral separation using a one-shot change detection methodology. Their results were most consistent with the predictions from the theory of off-sized perceptions (Gogel & Da Silva, 1987a). Moreover, the results did not agree with the position that visual angle is the predominant determiner of exocentric distance judgments (Levin & Haber, 1993; Matsushima et al., 2005). Specifically, when object size was varied between the source and target images, accuracy was reduced compared to trials where size did not change. This result was found using both a three-alternative forced-choice task (Experiment 1 & 3) and a distance reproduction task using the mouse (Experiment 2).

Another key prediction in extending Gogel's theory of off-sized perceptions to judgments of lateral separation is that separations should be processed in a way that is similar to perceived size (cf. Equations 8 & 9). Based on the SDIH, the perception of size and separation both rely on the visual angle of the target and the perceived depth of the target. The present experiment examined whether changes in object size affect line magnitude estimates and line length productions in a way that is consistent with the judgments of lateral separation from Experiment 1 to 3. In the present experiment, it was predicted that increases in object size should cause line lengths to be underestimated relative to trials where object size did not change. Conversely, it was predicted that decreases in object size should cause line lengths to be overestimated relative to trials where object size did not change.

In addition to examining the role that changes in object size have on line length estimates and productions (i.e., size judgments), this experiment also examined whether participants were able to rapidly estimate (and produce) lines using an object (i.e., a square) as a metric. Results from the congruent-change trials in Experiment 1 and 3 suggested that participants were rapidly encoding the separation using a ratio of object size to separation, referred to as an ad-hoc metric. The ad-hoc heuristic involves participants making a preliminary judgment by comparing these size-distance ratios instead of comparing relative separations (i.e., comparing visual angles). This ad-hoc heuristic would explain why participants were not correctly judging that distance changed in congruent-change trials. For instance, when both object size and inter-object distance decreased in proportion, familiar size cues would bias participants to judge that distance was farther while visual angle cues would bias participants to judge that distance was closer. Neither cue supported a judgment that distance was the same.

It was possible that in the congruent-changes trials from Experiment 1 and 3 participants automatically scaled the image (possibly in depth) despite instructions to judge the absolute separation between objects (cf. Figure 12 see also Rock & Ebenholtz, 1959). This scaling interpretation is similar to the ad-hoc heuristic because both are based on a proportionate change to both the size and distance of the stimuli. More specifically, both are based on the relative activation of the size of the squares and the distance between the squares. To control for this scaling interpretation (a relative size cue), only a single square was presented in the source and target images of the present experiment.

In the present experiment, participants performed two tasks. In the magnitude estimation task, a line was presented in the target image and participants decided how many squares (shown in the source image) would be needed to fill the line. In the line production task, participants used the mouse to produce (i.e., drag) a line that was equal in length to a certain number of squares (e.g., making a line five squares long). Object size either remained unchanged, was changed by .20° of visual angle, or the object was not present in the target image. This methodology was analogous to the no-change and size-change trials from Experiment 1 and 3.

Generalizing from the results of the first three experiments, it was hypothesized that farther line lengths would cause linear increases in RTs. While prior results have not identified a consistent effect of distance reproduction on RTs, the generation of an ad-hoc ratio implies that participants use a heuristic of counting the number of squares that would fill a previously-perceived distance. Baseline dragging speeds were collected for each participant to estimate the motor component of response times (Fitts' Law) in the line production task to partial out the motor dragging component (i.e., physical limitations of dragging duration) from the decision processes.

If the ad-hoc metrics heuristic is an effective method to judge distance, then it would be expected that the accuracy of line magnitude estimates and productions should be near ceiling levels. In addition, if perceived size and separation engage the same perceptual mechanisms, then for trials where size-changes occur, accuracy should be reduced compared to trials where no size-changes occur (reflected in relative over- and underestimation in the distance production task). This theorized reduction in accuracy would be consistent with the predictions from the theory of off-sized perceptions, and furthermore, reflect an inability to inhibit processing the size of the square in the target image despite task instructions requiring participants to do so (Makovski, Shin, & Jiang, 2006).

Method

Participants. Thirty Carleton University undergraduate students (10 women and 20 men, mean age = 21.65 years) were provided 1% psychology course credit for their participation. All participants exhibited normal or corrected-to-normal vision.

Materials. The experimental stimuli consisted of two sequentially-presented images. In the source image, a single square was located along the central vertical axis of the computer screen, 12 cm from the top of the screen. The square was one of three possible initial sizes (1.05°, 1.45°, or 1.85°). In the target image of both tasks, the square remained unchanged, its size was increased by .20°, its size was decreased by .20°, or it was not presented in the target image. These four conditions are depicted in Figure 19. In the line magnitude estimation task, the target image was a centered horizontal line. Its length was generated using multiples of object size, ranging from 2 to 9. In the distance production task, in the target image, a 64 point font digit (from 2 to 9) was presented 5 cm from the top of the screen. In addition, a 1 mm long horizontal line was presented 20.5 cm from the right edge of the screen. The participant dragged this line using the mouse.

Procedure. On each trial of the line production task, participants were instructed to produce the line using the object from the source image as a metric and the number in the target image as the ratio (i.e., the number of squares apart the distance had to be produced). Participants dragged the mouse until they believed the distance was accurately produced and then pressed the left mouse-button. The experimental software only processed horizontal input (left or right motion) from the mouse. Thus, it was impossible to drag the object up or down. For the line magnitude estimation task, participants were instructed to estimate the number of objects (from the source image) that it would take to fill the line in the target image (i.e., to round up to the nearest object). Responses were recorded by the right hand pressing a number on the keypad (1 to 9).

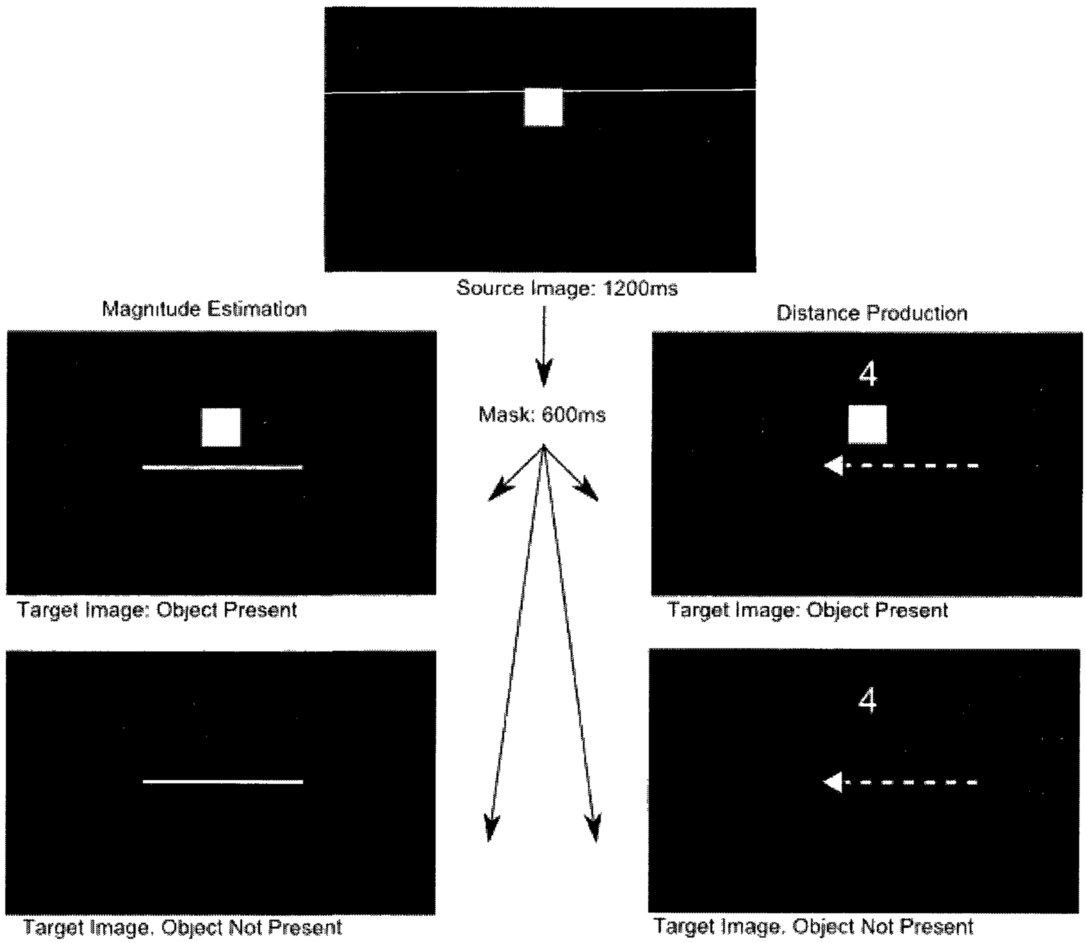

Figure 19. The figure presents sample stimuli from Experiment 4. The arrow in the distance production task represents the participant dragging a solid line out from a fixed point 20.5 cm from the right edge of the screen.

On each trial, the source image was presented for 1200 ms followed by a white noise mask for 600 ms. The target image was presented immediately after the mask disappeared. It remained visible on the screen until participants provided a response. Response times were recorded from the onset of the target image until the left mouse-button (for the distance production task) or keypad number (for the line magnitude estimation task) was pressed. After each response, the experimental software prompted participants to press the spacebar to continue to the next trial. Participants were instructed to use their left hand to press the spacebar to advance between trials and their right hand to drag the mouse or press the keypad number regardless of handedness. In total, participants completed 192 experimental trials, 96 in each of the distance production and line magnitude estimation tasks.

Participants initially completed an 18-trial drag-to-target task to model Fitts' Law (i.e., psychophysical dragging durations; MacKenzie, 1992). In this task, participants were instructed to horizontally drag out a line from a 2-pixel wide anchor located 20.5 cm from the right edge of the computer screen to a 2-pixel target located 2.5° - 15° to the left of the anchor (in 2.5° degree increments). Participants completed three replications for each visual angle. Task order was counterbalanced. The total duration for this experiments was approximately 35 minutes.

Results

Two participants were excluded from the data analyses because they had difficulties complying with task demands. The remaining 28 participants' results were entered into all available analyses. Results are reported with Greenhouse-Geisser adjusted values whenever sphericity was violated. All *p*s < .001 unless otherwise indicated, and all post-hoc analyses are reported with pairwise Bonferroni-adjusted values. A histogram of response times is available in Figure 25 (see Appendix A).

Line Production Task. Two separate 4 (change type: no-change, no-object, size-increase, size-decrease) x 8 (line length: 2-9 object-multiples) repeated-measures ANOVAs were conducted for deviation and Fitts' Law adjusted response times (in ms). Deviation was measured as the difference between the dragged line length and the expected length based on multiplying the size of the object presented in the source image by the number presented in the target image. Deviations for which the produced line length was too small (underestimation) are represented as negative (-) values and deviations for which the produced line length was too long (overestimation) are represented as positive (+) values. Data were collapsed across the factor of objects' initial size as was done in Experiment 2. A total of 13 trials (of 2688 total trials, or 0.48% of all trials) were excluded due to having either no recorded response times or dragging deviation more than 3 standard deviations from each participant's mean.

Using the baseline drag-to-target task, psychophysical dragging durations were partialled out from response times using Fitts' Law (as given in Equation 10). Assuming the size of the target (W) is 2-pixels wide, the baseline drag-to-target task generated values of 598 ms for the initial offset (a) and 217 ms for the resolution of the mouse (b). Entering the actual dragged line length (i.e., dragging distance D) into Equation 10 yielded the RT required for physical dragging durations (T). This equation accurately captured the pattern of participants' RTs (R = .95). According to MacKenzie (1992), an R value greater than .90 is an exceptional fit when examining human data. The offset (a) was higher than for MacKenzie, but it can be surmised that this finding was due to the increased difficulty of the task. The resolution of the mouse (b), however, was similar. This justified the assumption in Experiment 2 that dragging the resolution of the mouse was similar to the one used in MacKenzie. In summary, all RTs were adjusted using Equation 10 to partial out psychophysical dragging durations from participants' RTs.

The main effect of change type was significant for deviation, $F(3,81) = 12.62$, $MSE = 18.16$, $\eta_p^2 = .318$. Deviation was similar for the same object-present and no-object present (M = 1.24° and 1.29° respectively) with relative underestimation when object size was decreased (M = .83°, p < .001) and relative overestimation when object size was increased (M = 1.51°, p < .118). This result was consistent with the results of Experiments 1 to 3 and the predictions of the theory of off-sized perceptions. There was also a significant main effect of line length on deviation, F(1.46, 39.51 = 4.88, MSE = 18.62, p < .021, η_p^2 = .153, and a linear trend of increased line overestimation was obtained, F(1, 27) = 5.55, MSE = 120.89, p = .026, η_p^2 = .171. Because there was no line in the source image, this overestimation could not be due to any attentional feedback. In addition, having overestimation at farther line lengths would have been inconsistent with the predictions of the feedback hypothesis. Finally, the change type x line length interaction was not significant, F(9.085, 245.29) = 1.30, MSE = 2.59, p = .239, η_p^2 = .046.

Further supporting the predictions of the theory of off-sized perceptions, the main effect of change type was also significant for RT, F(3,81) = 13.27, MSE = 24900000, η_p^2 = .329. Responses to no-object trials were significantly faster (M = 2155 ms) than the same-object, size-increase, or size-decrease trials (M = 2825 ms, 2783 ms, and 2851 ms respectively; ps < .001). Combined with the deviation results, participants appeared unable to inhibit attending to the size of the object in the target image, which influenced their representation of the object from the source image. Finally, unlike the initial distance results in Experiment 2, there was a significant main effect of line length on RT, F(2.01, 54.38) = 32.64, MSE = 491000000, η_p^2 = .547. Similar to the accuracy results, a linear RT increase was found, F(1,27) = 47.06, MSE = 963000000, η_p^2 = .635. This implies that participants were not making a singular mental judgment of the line length and then dragging-out the line, but instead was consistent with participants using the object as a ruler and counting out (i.e., processing) the line in segments.

While the previous results were consistent with the predictions from the theory of off-sized perceptions, the substantial overestimation of line lengths suggests that the ad-hoc heuristic was not an effective cue to distance production. Another possibility, however, is that the size of the square was misperceived. Thus, an ad-hoc heuristic may have been accurately applied to a misperceived square size. To examine this possibility, a measure of participants' perceived size was calculated by dividing produced line length by the number of objects (2-9) participants were instructed to drag out the line. Initial object size was overestimated by .40° at the 1.05° initial size, by .32° at the 1.45° size, and by .28° at the 1.85° size (see Figure 20).

To support the prediction that the size of the square was misperceived, a linear regression was conducted using expected line length to predict produced line length (see Haber & Levin, 2001). The regression equation was of the form:

$$produced\ length = (B)\ expected\ length \qquad (11)$$

The model was an very good fit, with an R^2 predicting 72% of the variance in produced line length, $F(1, 2673) = 6860$, $p < .001$. The regression model is described in Equation 12:

$$produced\ length\ = (1.02)\ expected\ length + 1.074 \qquad (12)$$

The regression coefficient did not differ from unity ($B = 1.02$, $p > .1$). The positive value of the intercept (y = 1.074°) and strong model fit indicate that perceived size was consistently overestimated and line lengths accurately produced using the misperceived object size as the metric.

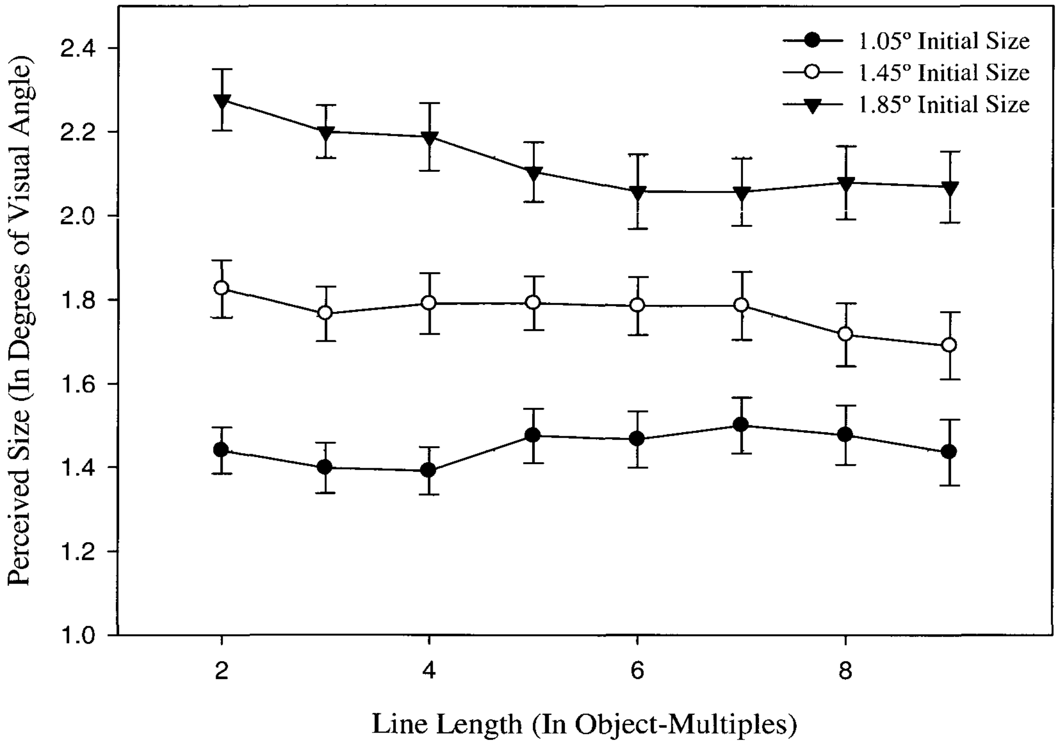

Figure 20. The interaction between perceived size and line length. Error bars represent standard error. The reference lines represent the mean values

Line Magnitude Estimation Task. Two separate 4(change type: no-change, no-object, size-increase, size-decrease) x 7(line length: 2-8 object-multiples) repeated-measures ANOVA were conducted for accuracy (i.e., proportion correct) and response times (in ms). Data were collapsed across the factor of objects' initial size. The farthest (9 object-multiples) line length was excluded from analyses because participants could not overestimate length (i.e., they could not respond "10" or higher using the keypad). A total of 36 responses (of 2352, or 1.53% of all trials) were excluded due to having either no recorded response or response times exceeding 3 standard deviations from the participants' mean.

Unlike the distance production task, there was only a marginal effect of change type on accuracy, $F(3, 81) = 2.29$, $MSE = .25$, $p = .084$, $\eta_p^2 = .078$. Surprisingly, having the same object present in the target image ($M = .42$) did not significantly improve accuracy relative to having no object present ($M = .46$). Even more surprisingly, having a different-sized object present in the target image did not significantly reduce accuracy ($M = .49$, .41 for object-size decreased and increased, respectively). However, when object size decreased, accuracy was in fact significantly higher compared to when the same object was present in the target image, ($p < .01$). It is likely that the increased accuracy for decreased object size was due to the systematic overestimation of object size discovered in the distance production task. The theorized off-sized perception caused by decreasing object size (by .20°) would partially offset the overestimation (from .28° - .40° in line production task) determined from the distance production task, resulting in overall higher accuracy.

The main effect of line length was significant for accuracy, $F(6, 162) = 39.59$, $MSE = 4.59$, $\eta_p^2 = .595$. Post-hoc contrasts indicated that accuracy linearly decreased as line length increased, from $M = .78$ at 2-objects to $M = .24$ at 8-objects, $F(6, 162) = 23.96$, $MSE = 46200000$, $\eta_p^2 = .470$. The interaction between change type and line length for accuracy was not significant, $F(18, 486) = 1.12$, $MSE = .07$, $p = .329$, $\eta_p^2 = .040$.

Despite no main effect of change type on accuracy, there was a significant effect of change type on RT, $F(3, 81) = 12.81$, $MSE = 5960000$, $\eta_p^2 = .322$. Participants responded significantly faster in the no-object trials ($M = 2762$ ms) than either the same object or size-changed object trails ($M = 3058$ ms, 3102 ms, 3148 ms for same object, increased-size, and decreased-size, respectively; $ps < .001$). This 400-500 ms increase in

RTs seems to indicate that participants were processing the size of the object in the target image and is consistent with the time-course identified in prior research (Vogel et al., 2006). The main effect of line length on RT was also significant, $F(6, 162) = 23.96$, $MSE = 46200000$, $\eta_p^2 = .470$. Post-hoc contrasts indicated that RT linearly increased as line length increased (from $M = 2026$ ms at 2-objects long to $M = 3645$ ms at 8-objects long), $F(1, 27) = 33.63$, $MSE = 262000000$, $\eta_p^2 = .555$. This implies some additional processing consistent with the ad-hoc metrics heuristic (i.e., counting squares), because baseline key press times did not significantly vary. Similar to the accuracy results, the interaction between change type and line length for response time was not significant, $F(18, 486) = 1.15$, $MSE = 760000$, $p = .297$, $\eta_p^2 = .041$.

To facilitate a comparison with the patterns of errors analyses from Experiments 1 and 3, a measure of the degree of over- and underestimation was also examined. It was calculated by subtracting the participants' estimated line length from the actual line length (using the objects as the metric). When the estimated line length was less than the actual line length (underestimation), the response difference was represented as a negative (-) value. Conversely, when the estimated line length was greater than the actual line length (overestimation), the response difference was represented as a positive (+) value. These response differences were analyzed by running a 4(change type: no-change, no-object, size-increase, size-decrease) x 7(line length: 2-8 object-multiples) repeated-measures ANOVA.

Participants consistently underestimated their distance judgments. The degree of underestimation significantly varied by change type, however, $F(3, 81) = 24.89$, $MSE = 7.74$, $\eta_p^2 = .480$. Post-hoc tests revealed that participants underestimated line length in the no-change and no-object change types (M = -.38 and -.27, respectively). The distance production task identified that object size was overestimated, which is consistent with the line length underestimation in the present task. For instance, if a line was physically 6-objects in length, then if object-size was overestimated by 16% participants would perceive that the line was in fact only 5-objects long. In addition, consistent with the theory of off-sized perceptions, participants relatively overestimated distance when object size was reduced (M = .01; ps < .002). Interestingly, increasing object size did not significantly increase the degree of underestimation (M = -.48; p = .395).

The RT results were consistent with the accuracy results. The main effect of line length was significant, $F(2.65, 70.87) = 33.37$, $MSE = 27.45$, $\eta_p^2 =.553$. Post-hoc contrasts indicate that 2- and 3-object line lengths were accurately perceived (M = -0.03). Farther line lengths, however, showed linearly increased underestimation, $F(1, 27) = 56.80$, $MSE = 66$, $\eta_p^2 =.678$. Although the change type x line length interaction showed a trend, it did not achieve significance, $F(10.33, 275.95) = 1.76$, $MSE = .68$, $p = .065$, $\eta_p^2 =.061$.

Discussion.

The results of changing object size in both the line production and line magnitude estimation tasks provided evidence that object size influences both line estimates and productions in a manner that is consistent with the theory of off-sized perceptions. In particular, when object size was increased in the target image, line estimates and productions were overestimated. Conversely, when object size was decreased in the target image, line estimates and productions were underestimated. These results were similar to the over- and underestimation of lateral separation found in Experiments 1 to 3.

This suggests that both object size and separation use similar perceptual resources. Thus, similar to Experiment 1 and 3, changing the size of the square in the target image altered both the line and separation judgments in a way that is analogous to the altered size judgment in the Ebbinghaus illusion (cf. Figure 2; changing the size of the outer circles alters the size judgment of the centre circle).

In addition, the line production results suggested that object size was systematically misperceived. Object size was overestimated by .28° to .40° of visual angle. These results were also consistent with the underestimation found in the line magnitude estimation task. This overestimation of object size was consistent with the attentional feedback hypothesis. The lack of substantive evidence in Experiment 3, however, reduces the likelihood of this explanation being correct. Still, there must be some process underlying this misperception of object size. While not providing an explanation of this overestimation, Carlson (1960) also found that object size was overestimated under objective task instructions. The present task, however, used task instructions consistent with apparent task instructions.

Moving on to the particular predictions for the present experiment, both the line production and line estimation results were consistent with the idea that participants were adopting a heuristic where object size was used as a metric to encode separation. This was referred to as generating an ad-hoc metric. In particular, participants' results were consistent with an accurate application of the ad-hoc metrics ratio (i.e., perceived object size to line length) once the systematically overestimated object sizes were taken into account.

Interestingly, participants could not inhibit processing the size of the object in the target image despite task instructions to judge or produce line lengths based on the object in the source image. In both the line estimation and line production tasks, participants responded relatively faster and more accurately when no object was present in the target image as opposed to when an object was present. This apparent advantage for the no-object trials suggests that participants were unable to ignore the second object even though it was an unreliable metric for the tasks. Indeed, for 75% of trials, the source and target images were different. Furthermore, change type conditions were presented in mixed trials. Thus, the target image could not be trusted to provide an accurate representation of the source image.

Beyond 3 objects apart (~4° of visual angle), line magnitude estimates were greatly underestimated in the line estimation task and deviations increased significantly in the line production task. While the underestimation of line lengths was consistent with the underestimation of exocentric distance judgment in Levin and Haber (1993), Loomis et al. (1992), and Matsushima et al. (2005), these studies generally found less underestimation at relatively farther visual angles. The current experiment, however, generally found more underestimation at relatively farther visual angles. One difference between their studies and the current experiments is that they examined larger visual angles than the present experiment (from 10° - 90° of visual angle compared to 2° - 16° of visual angle). When matching trials with similar visual angles between studies (between 10° - 16° of visual angle), however, the pattern of underestimation was similar. It may then be that the current line magnitude estimation task extends Levin and Haber's results to relatively closer separations.

Despite having overall low accuracy and high deviation due to a misperceived object size, the results of the present study indicated that participants adopted an ad-hoc metrics heuristic, and that this heuristic was an effective method to make line length judgments. Evidence for the ad-hoc heuristic was found when participants' results were consistent with their using the size of an object as a ruler to count out the number of objects that would fit in a given distance. This is equivalent to generating a ratio of object size to inter-object separation. Participants' accurate application of a metric in the distance production task further suggested that using object size as a metric was an effective heuristic for determining size and distance. Furthermore, the linearly increasing RTs with longer line length judgments suggested that some additional processing was occurring. This additional processing is also consistent with an ad-hoc counting strategy. Nonetheless, the results do not necessarily entail that participants were consciously applying the ad-hoc heuristic; it could certainly be processed automatically. A final piece of evidence supporting the use of an ad-hoc heuristic comes from research on trans-saccadic memory (memory stored between eye saccades). It shows that, even when an image of a scene is displaced by up to 1.2° of visual angle or contracted by up to 20%, these changes often go unnoticed (McConkie & Currie, 1996). This lack of change detection is consistent with the idea that the ratio of the relative sizes of objects and distances between them being unchanged after the displacement or contraction.

In summary, Experiment 4 further supports the conclusions of Experiments 1 to 3: changes in object size influence judgments of lateral separation as predicted by Gogel and Da Silva's (1987a) theory of off-sized perceptions. In addition, the current experiment has extended these results to line estimates and line productions, suggesting that judgments of separation and perceived size judgments are processed similarly. This common processing of separation and perceived size was a key prediction in extending the theory of off-sized perceptions to exocentric distance judgments (cf. Equation 9).

GENERAL DISCUSSION

The present research investigated the influence of object size on judgments of lateral separation. Prior research has argued that visual angle is the predominant cue in exocentric distance perception (Levin & Haber, 1993; Matsushima et al., 2005). Under this visual angle prediction, changes in object size should not influence judgments of lateral separation. Studies on size cues to judgments of relative depth, however, have shown a varied but significant influence of object size across various task instructions (Epstein, 1963; i.e., objective or apparent) and methodological implementations (Carlson & Tassone, 1971; Park & Michaelson, 1974; Mershon & Gogel, 1975). Assuming judgments of depth and separation subsume similar processes, it is thus likely that object size should influence judgments of separation. Gogel and Da Silva (1987a) presented evidence that direct judgments of distance could be dissociated from the indirect perception of distance, which lead to their theorizing a two-process *theory of off-sized perceptions*. The theory of off-sized perceptions predicts that changes in object size should affect inter-object distance judgments. A one-shot change detection methodology (Phillips, 1974; Cole et al., 2003) was adopted to examine the role of object size judgments of lateral separation. Four experiments identified that changes in object size affect both the judgment and reproduction of both separation (Experiments 1 to 3) and line length magnitudes (Experiment 4) consistent with the predictions of the theory of off-sized perceptions.

The remainder of this discussion summarizes the main results of the four experiments. Following this summary, some implications of adopting the theory of off-sized perceptions will be discussed, including a broader analysis of the implications of adopting a dual-process model for size and distance perception. Finally, the original contributions of the change-detection methodology as a means of measuring size and distance judgments will be analyzed and some future studies will be proposed.

Summary of Experiments

Experiment 1 used a three-alternative forced-choice "closer-same-farther" paradigm to examine the influence of object size on judgments of lateral separation. Changes in object size significantly influenced participants' judgment of separation consistent with the predictions of the theory of off-sized perceptions. In particular, when object size increased, participants underestimated the separation between the objects. Conversely, when object size decreased, participants overestimated the separation between the objects. Response times were significantly longer in trials where object size changed, implying that participants were processing this change. Furthermore, trials with correct responses were responded to quicker than trials with incorrect responses, implying that some cue conflict occurred. In addition, participants were three times as likely to judge the distance "farther" than "closer" in trials where neither size nor distance was changed. This was attributed to an attentional feedback hypothesis, where participants' attention was biased towards a resting state during the pattern mask. Finally, when size and distance changed in proportion, participants were biased to judge the distance unchanged, suggesting that participants were rapidly adopting a heuristic comparing object size to separation (referred to as generating an ad-hoc metric).

Experiment 2 extended the design of the one-shot change detection task requiring a distance reproduction response using the mouse. This response provided more evidence as to the quantitative changes in distance judgments due to changes in object size. While changes in object size significantly influenced distance reproductions, the deviations in distance were only 13% to 20% of those expected from familiar size cues. This partial dragging deviation was likely due to conflict between familiar size cues and the separation specified by visual angle, and was consistent with the small yet significant effect of familiar size cues on egocentric depth judgments (Gogel, 1981; Gogel & Mertens, 1968; Mershon & Gogel, 1975). Furthermore, participants were also biased to overestimate relatively closer separations and underestimate relatively farther separations. This deviation due to different initial separations was consistent with the predictions of the attentional feedback hypothesis.

Experiment 3 replicated the forced-choice response from Experiment 1, but extended the design to include varied pattern mask durations and the inclusion of two interference tasks. The central results of Experiment 1 were replicated: object size significantly influenced distance judgments. The pattern mask condition identified that longer mask durations increased bias to judge the separation "farther" rather than "closer" when object size and separation remained unchanged. The results of the 300 ms pattern mask trials, however, were inconsistent with the predictions of the attentional feedback hypothesis. Attention should not shift at mask durations less than 500 ms, thus, there should have been no farther-bias at the 300 ms mask duration. In addition, the interference tasks suggested that it was possible to load up memory such that size cues were less effective in distance judgments. Unfortunately, the effect of the interference task was marginal. In addition, longer pattern mask durations appear to have subsumed the effect of the interference task. Again, similar to Experiment 1, RTs were increased when size cues conflicted with separation (i.e., size-change and congruent-change trials).

Finally, Experiment 4 adopted line magnitude estimation and line production tasks, the results suggesting that judgments of lateral separation were processed similar to judgments of perceived size (i.e., line lengths). In particular, line length judgments were affected by changes in object size despite task instructions to rely on object size in the source image. Furthermore, object size was systematically overestimated in both the line magnitude estimation and line production tasks. When this overestimation was taken into account, participants were extremely accurate in using object-size as a metric consistent with the ad-hoc metrics heuristic.

Implications of Off-Sized Perceptions in Exocentric Distances

The results of the four experiments support the extension of the theory of off-sized perceptions to judgments of lateral separation. Judgments of lateral separation require at least two reference points from the observer to frame the inter-object distance. Based on the results of the present research, the size of these anchors should influence perception of the separation just as the size of adjacent circles influences the size of a central circle in the Ebbinghaus illusion. As seen in Figure 21, relative size cues appear to influence not only the sizes of central circles in the Ebbinghaus illusion, but also the perceived separation between the outer circles.

Conversely, egocentric distance perception (i.e., depth perception) only requires one reference point (an object in depth) from the observer. Because there are more anchors in exocentric distance perception and the processes involved in exocentric distance and size perception are similar, it stands to reason that exocentric distance judgments should be more heavily influenced by familiar size cues than egocentric distances.

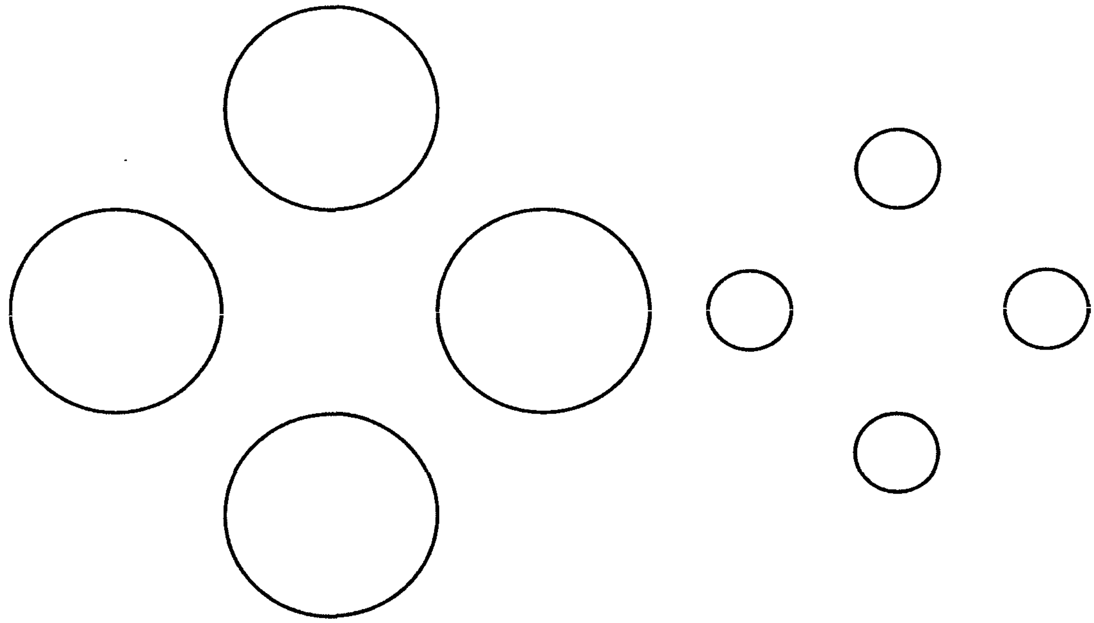

Figure 21. This image represents a hybrid Ebbinghaus / Muller-Lyer illusion. Instead of misperceiving the size of two central circles, there appears to be a small illusion between the separations of the larger and smaller circles. The separation appears slightly smaller for the larger circles than for the smaller circles, even though their separation is the same (the separation is equal to the size of one of the larger circles).

If familiar size is an effective cue to judgments of lateral separation, then the accuracy of perceived and familiar size is an essential factor in modeling the processes implicated in distance judgments. Haber and Levin (2001) examined the consistency of observers' size judgments across 30 common objects and found more accurate distance judgments (especially at farther 50 - 100 m distances) for token invariant objects than either token variable or unfamiliar objects. Token invariant objects have limited variability in their range of sizes, such as tennis rackets and pop cans. Token variable objects have increased variability in their range of sizes, such as Christmas trees, chairs, and televisions. While size influenced distance perception, distance perception did not influence the judged size of familiar objects. Size judgments instead appeared to be based primarily on familiar size, and not perceived size.

One difference between judgments of size and separation is that, in the real world, there are more familiar sizes than familiar separations. For instance, people implicitly recognize the size of many objects, such as a large pizza box (~ 45 cm), a beer bottle (~ 20 cm), or the average length of a car (4 - 5 m). On the other hand, people do not tend to implicitly recognize the distance between objects because there are very few standardized distances in the environment. Exceptions to this rule are the boundaries in sports. For instance, the distance between the free-throw line and the basket is 4.57 m (15 ft) in basketball.

According to the theory of off-sized perceptions, an off-sized perception occurs when the perceived size of an object conflicts with its familiar size. This off-sized perception can calibrate distance judgments at farther depths, where depth cues are impoverished (resulting in an underestimation of perceived size and exocentric distance). Because there are rarely familiar exocentric distances, the calibration of exocentric distances relies on familiar size cues from the anchoring objects (cf. Ebbinghaus illusion) or other nearby objects (cf. adjacency principle; Gogel, 1965a).

Why did the present study find a strong influence of object-size on distance perception in contrast to multiple studies arguing that visual angle was the predominant cue to exocentric distance perception? In Levin and Haber (1993), Matsushima et al. (2005), and Aznar-Casanova et al. (2009), the anchors were unfamiliar objects that were the same size (either wooden posts or computer generated cylinders). Moreover, they were presented only once. Thus, there were no size cues. In Haber and Levin (2001), familiar objects were used, but none of the objects presented were off-sized variants (e.g., a 40 cm tall beer bottle, double the height of the standard 20 cm high bottle). Hence, because object size was controlled in prior research, there was no possibility for a relative or off-sized perception as a size cue to calibrate distance judgments. It is thus not surprising that their results show only a limited effect of object size on distance perception.

In addition to controlling for object size, a broader difference is that Levin and Haber (1993) and Matsushima et al.'s (2005) experiments were conducted in a rich natural environment. The additional cues provided in naturalistic scene may offset the effectiveness of size cues on distance perception. While a single off-sized object may strongly calibrate size or distance judgments in a reduced cue environment, it may not be effective as the only size-cue conflict in a naturalistic scene (where grass, trees, and buildings all provide consistent cues to a particular size or distance).

The Anisotropy of Visual Space

Gogel (1972) argued for a separation of the processes engaging egocentric and exocentric perceptions because the factors determining each perception are different. Egocentric distance judgments, especially those of the primary process, are based on hardwired oculomotor cues such as accommodation, extra-ocular cues such as convergence (Gogel & Tietz, 1979, 1980), and perspective cues (Toye, 1986). Exocentric distance judgments have been thought to rely on visual angle perception (Gogel & Mertens, 1968; Levin & Haber, 1993; Matsushima, de Oliveira, Ribeiro-Filho, & Da Silva, 2005). Evidence supporting the separation of egocentric and exocentric processes is that the general accuracy of egocentric and exocentric distance judgments is different (Aznar-Casanova et al., 2008). This difference in accuracy is called the *anisotropy of visual space*, and is characterized by a relative underestimation of farther egocentric distances and a relative overestimation of farther exocentric distances (Loomis, Da Silva, Fujita, & Fukusima, 1992; Matsushima et al., 2005; Toye, 1986; Wagner, 1985).

In support for the separation of exocentric and egocentric processes, Matsushima et al. (2005) had participants judge the relative separation between stakes in an open field (also see Levin & Haber, 1993). The stakes varied in both lateral separation (i.e., visual angle varied between 10 – 90 degrees) and egocentric distance (23 and 36 m). Visual angle was the determining factor for exocentric distance perception with nearly veridical perception at visual angles above 70 degrees. Egocentric distance did not significantly affect exocentric distance judgments, although there was a trend to more greatly underestimate exocentric distance at 36 m compared to 23 m away. Additionally, at visual angles below 30 degrees, there was an increasing distance underestimation. Finally, at visual angles above 70 degrees, there was increasing distance overestimation. Matsushima et al. concluded that at visual angles below 70 degrees, non-perceptual factors such as relative size cues and the equidistance tendency influenced exocentric distance perception (consistent with the adjacency principle; Gogel, 1964, 1965). They further concluded that because egocentric distance did not affect exocentric distance judgments, and because the results were consistent with the anisotropy of visual space, this supported the separation of egocentric and exocentric processes.

Sterken et al. (1999), however, found that a concurrent egocentric shift reduced the accuracy of exocentric distance judgments to near-chance levels. Similarly, a concurrent exocentric shift reduced the accuracy of egocentric judgments to near-chance levels. It was interesting to note that without cue conflict, the accuracy of egocentric and exocentric judgments was similar (.70 and .74, respectively). This proportion correct was similar to the proportion correct of distance- change trials in the present research.

Furthermore, an earlier Loomis et al. (1992) study had also observed the anisotropy of visual space phenomenon. Loomis et al. did not, however, support the segregation of egocentric and exocentric perception. Instead, they argued for only the partial independence of exocentric from egocentric perception. This partial independence can be captured by the differential influence of visual cues on egocentric and exocentric perceptions. For instance, relative size is a strong cue to exocentric distance but only a minor determiner of egocentric distance (Gogel, 1965). This partial independence may also be captured by a hierarchical processing of egocentric and exocentric perceptions (Aznar-Casanova et al., 2008; Gallistel & Cramer, 1996). For instance, it may be possible that egocentric distance perception is required prior to processing exocentric perceptions. That is, one may need the relative depth information to the objects forming the ends of the inter-object distance before an exocentric judgment can be made (Aznar-Casanova et al., 2008). Under this interpretation, egocentric and exocentric processes are stages of output along a serially-processed continuum.

Re-Examining the Evidence for Dual-Process Models

The principal evidence for a dual-process model of size and distance perception was Gogel's head-motion technique (Gogel 1976, 1998; Gogel & Da Silva, 1987a, b; Mershon & Gogel, 1975). The advantage of this technique was that it was able to dissociate a relatively veridical measure of perceived distance from direct reports of distance, which were affected more by familiar size cues. The measure of perceived distance, however, was indirectly generated from perceived motion. This has led some researchers (e.g., Wagner, 2005) to question whether Gogel's methodology really had dissociated perceived distance from judgments of distance, per se. For instance, no other prior research has found a similar dissociation using a variety of responses from verbal reports, pointing, distance reproduction, or matching tasks.

The present research utilized a selective interference methodology in an attempt to dissociate a relatively veridical measure of perceived distance from the effects of prior knowledge such as familiar size cues. The results of this task were only marginally significant. The probable reason for this marginal finding was that the line-art drawings used as interference stimuli may have been too different from the visual stimuli in the tasks. In addition, the line-art drawings were rehearsed over several trials. Consequently, to increase the load on visual short-term memory and limit participants' ability to generate a heuristic to encode the interference stimuli, further research should use a recognition task with a grid of squares as the interference condition, similar to a dot-pattern recognition task. Instead of a matrix of dots (i.e., circles), a matrix of squares should be used. In addition, participants should be presented with a new matrix of squares for recall after each trial. These modifications to the interference task should further inhibit familiar size processing and reduce the effectiveness of size cues on distance perception.

The Role of Object Size in the Mapping of Visual Space

The external world is generally seen as having an objective reality, where physical space can be effectively and consistently translated into a system of coordinates. One question is whether our perception and subsequent representation of physical space can be similarly translated? The internal visual representation of physical space is called *perceived space*. For instance, given the particular location of an observer viewing a scene, can his perception of the distances between objects be accurately mapped onto the actual physical distances between the objects? In other words, is it possible to determine a function that can accurately predict the layout of our representation of the world from the actual layout of the physical world?

Substantial research has been undertaken to identify a function which maps visual space onto physical space. It has been suggested that this research has been attempting to generate a *geometry of visual space* (Wagner, 1985, 2006). To date, no single geometry has been identified that adequately captures visual space. For instance, Intraub (1997) concluded that observers used no scene-independent metric system (such as visual coordinates) when judging physical space, but instead relied on local information within the scene. Similarly, Cuijpers et al., (2002) examined whether two lines at different separations would be judged parallel, and found that distances across successive trials could not be described by the same visual geometry. They concluded that the geometry of visual space must be locally-defined at the time of viewing. Rensink (2002) also concluded that, "more generally, it appears that the detailed contents of successive presentations – including successive fixations – can never be added, compared, or otherwise combined in their entirety, thereby ruling out any large-scale accumulation of information" (p. 264). Finally, Wagner (2006) conducted a meta-analysis of vision research literature and concluded that there was no underlying geometry of visual space, but instead that multiple geometries should be studied.

This difficulty in finding a single geometry to capture visual space seems incongruous with results from mental scanning and mental rotation studies. For example, in mental scanning tasks, several landmarks are studied in a pre-arranged configuration until their locations are memorized. For each trial, a specific landmark from the map is visualized and, when hearing the name of a second landmark, the participant has to mentally follow a visualized dot across the distance between landmarks and press a button when scanning is complete. Studies have found a linear correlation between response time and distance between landmarks (Kosslyn, Ball, & Reiser, 1978; Kosslyn, 1994; Cocude, Mellet, & Denis, 1999; Denis & Kosslyn, 1999). Similarly, in mental rotation tasks, participants are asked to compare images of two 3D objects and judge if they are the same image or if they are mirrored imaged. When the objects compared are rotations of each other, response times are linearly proportional to the angle of rotation (Shepherd & Metzler, 1971; Metzler & Shepard, 1974). This linear increase in response times with both mental scanning and mental rotation tasks has similarly been interpreted as if the mental representation of our visual perception is isomorphic with our perception.

The theory that there is some representational isomorphism with perception is not without its limitations, however. The linear correlation between mental scanning and distance has been shown to be highly task and instruction-dependent. When the participant is asked to trace the distance by mentally following a dot along the distance, then the mental scanning times are linearly correlated with distance with a coefficient of determination up to 0.97 (Kosslyn et al., 1978). When this dot-following heuristic is left out of the instruction, a much lesser (or no) linear correlation is evidenced (Pylyshyn, 1981, 2000). Furthermore, if a participant is asked to imagine "jumping" from one landmark to another rather than "scanning", no correlation between response times and landmark distance are found, presumably because no "scanning" occurred within the participant's mental representation (Pylyshyn, 2002). This stands in contrast with previous research indicating that it was not possible to eliminate mental scanning effects

(Kosslyn, 1994). Furthermore, Richman, Mitchell, and Reznick (1979) conducted a mental scanning test similar to that of Kosslyn et al. (1978), but the distances between landmarks were written on the map as numbers. In the critical condition, the distances written were not in proportion to the actual distance between landmarks. Participants' scanning effects accorded with the distances written on the map as opposed to the actual distance. This incongruous result identifies how task expectancy affects mental scanning and limits a purely isomorphic interpretation between perception and imagery.

Evidence from the current study identified that both the familiar size of objects and the relative size between objects influence the perception of distance. The influence of object size on the perception of distance may account for this lack of a unified geometry of visual space. For instance, in the size-change trials in Experiments 1 and 3, visual angle remained constant but object size varied. Participants tended to report that the distance between the objects was closer when object size increased and farther when object size decreased. The physical distance between the objects did not vary, however. Looking purely at the inter-object distance, there appears to be no geometry (i.e., no function) that translates participants' distance judgments onto actual physical distances. The inclusion of size cues onto distance perception, however, could account for this apparent lack of a geometry mapping perceived space onto physical space.

For instance, Copernicus originally proposed that the orbits of the planets were perfect circles around the sun. This "perfect circles" theory, while generally accurate, did not predict certain distortions when the planets were in the phase of their orbits nearest and farthest the sun. Evidence eventually showed that orbits of the planets were actually elliptical. Once Kepler (and later Newton) determined that gravity affected the orbits of the planets (a function of the mass of the other planets and the sun), then the elliptical nature of the orbits could be explained (Hyman, 1993). Analogous to the movement of planetary bodies, mapping "distortions" in the geometry of visual space will not be possible until size cues (analogous to gravity) are incorporated into the distance mapping function. Similarly, just as the mass of the sun alters the physical orbit of nearby planets, the relative and familiar size of nearby objects may alter the perceived distance between them.

These local influences of familiar and relative size cues are consistent with an ad-hoc metrics heuristic being used to judge distance. Supporting an ad-hoc heuristic, McKee and Welsh (1992) found that participants were able to quickly learn ordered (but arbitrary) reference systems when judging the size of objects (analogous learning different ad-hoc metrics). An implication of ad-hoc encoding of distances is that distance comparisons should be rapid and relatively accurate when a heuristic employs a single metric (e.g., comparing a distance two car-lengths away compared to three car-lengths away). Judgments should be difficult and more prone to errors, however, when a heuristic employs different metrics (e.g., comparing two car-lengths to four bicycle-lengths).

A difficulty of including object size as a factor in determining a singular geometry of visual space is that it requires not only an explanation of how a single object affects perceived distance, but also an explanation of how multiple objects interact with each other's perceived size and perceived exocentric distance. It is thus possible that the inclusion of object size as a factor in the geometry of visual space could greatly increase the complexity of the mapping function. For instance, if observers use the size of an object to generate a local ad-hoc metric, then visual space should be distorted based on which object(s) are used. In addition, the location of the objects within the scene could also be important, as the effectiveness of relative size cues (such as an ad-hoc heuristic) is based in part on the distance between objects (due to the adjacency principle). In summary, the influence of object size on distance judgments can explain to a certain extent the failure of prior research to find an independent metric of visual space. The inclusion of object size as a factor in determining the geometry of visual space, however, does not come without its own set of complications.

Original Contributions of the Change Detection Task

The current research adopted the one-shot change detection methodology to study the influence of object size on judgments of lateral separation. Participants were able to accurately detect changes in separation in the absence of changes in object size, suggesting that the task accurately measured what was intended, namely changes in lateral separation. The original contributions of the change detection methodology in the present research were the recording of response times and the adoption of multiple kinds of responses. The majority of prior research on distance perception (i.e., visual alley and head-motion tasks) did not collect or analyze response time data. An advantage of RTs is that they provided an indirect measure of relative processing demands, and could thus help tease apart different processes (as was seen in the relatively faster response for correct vs. incorrect responses in Experiments 1 and 3).

In addition to the RT results, the present methodology allowed for the recording of several kinds of responses, which provided converging evidence for the influence of object on judgments of separation. In particular, by adopting a three-choice closer-same-farther response, it was possible to determine not only participants' overall accuracy, but the particular patterns of errors participants were making. This made it possible to determine that participants' tendency, for instance, was to judge that separation was closer when object-size increased. This made it possible to determine that the reduction in accuracy was consistent with relative size cues (and the theory of off-sized perceptions) and inconsistent with a stimulus averaging hypothesis. Furthermore, the present research found evidence for some processing occurring during the pattern mask. In particular, participants were three times more likely to incorrectly judge that the distance was farther in the target image when in fact neither the size nor separation had changed. This was initially attributed to an attentional feedback hypothesis; however, the results from the 300 ms pattern mask duration from Experiment 3 precluded this interpretation. Farther pattern mask durations, however, exacerbated this "farther" bias.

In addition, a distance reproduction response provided a more quantitative measure of the influence of object size. This influence was less than 20% of that predicted by size cues, indicating that size cues were conflicting with a more veridical representation of size (assumed to be based on angular size). In summary, the change detection methodology provided evidence for multiple processes by expanding on a more traditional same-different response used in stimulus discrimination tasks.

Future Work

The current research has determined that object size significantly influences judgments of lateral separation consistent with the predictions of the theory of off-sized perceptions. Nonetheless, several findings will require additional research. In particular, there has been only inconclusive and contradictory evidence for an attentional feedback hypothesis. In particular, in Experiment 1 and 3 participants were three times as likely to judge that the separation was "farther" than "closer" in the target image for trials where size and distance were unchanged. This bias, however, was only present at relatively farther separations. Similarly, there was a tendency to underestimate relatively farther initial separations (resulting in an incorrect "farther" judgment). It was determined that that this underestimation only occurred for separations greater than ~3.7° of visual angle. This is coincidentally the position of ocular rest. These results were consistent with participants' attention shifting to a natural resting state during the pattern mask since there was no object to focus on when viewing the computer screen. It was further theorized, based on the pattern of underestimation, this resting state of attention correlated with the resting state of vision. However, in Experiment 3 there was still a bias to underestimate farther separations at the 300 ms pattern mask duration, which theoretically should have eliminated participants' ability to shift attention. Still, the bias was reduced at the 300 ms pattern mask duration, and exacerbated at longer mask durations. Whether or not attention is directly responsible for the underestimation of relatively farther separations, the cause of this bias still needs to be addressed.

Combining eye-tracking and the change detection methodologies would provide more direct information both about the relative position of the eyes as well as participants' perceived visual angle (de Grave et al., 2006). In particular, participants' fixations could be measured during the pattern mask, possibly quantifying a possible shift in attention. While attention and fixation are not identical processes (e.g., one can focus attention to a region of space not currently fixated upon), they are correlated. For instance, it is likely one would focus his or her attention to a region currently near a fixation, as this is where the highest resolution visual information would be located.

In addition, the effectiveness of familiar size cues needs to be more extensively explored. In the current research, the familiar size cue was based on the successive presentation of similar stimuli, where the initial presentation of the stimulus serves as the familiar size to compare against subsequent presentations. The repeated presentation of squares, however, has low external validity because two-dimensional squares are not a natural "kind" of object seen in the world. In addition, the successive presentation of unfamiliar objects was not what was traditionally used as "familiar" in prior research (except Gogel, 1998). To increase the external validity of the stimuli, they should be extended to objects more traditionally seen as familiar, such as the list of token-invariant objects from Haber and Levin (2001).

Furthermore, while the size-change results of Experiments 1 and 3 were inconsistent with a stimulus-averaging account (decreased size caused "farther" judgments, stimulus averaging would assume "closer" judgments), the deviation results of Experiment 2 were consistent with stimulus averaging. In Experiment 2, changes in object size appeared to cause a relatively fixed amount of deviation as opposed to a proportional change in deviation. For instance, according to the theory of off-sized perceptions, a change in object size should cause more deviation at farther separations than closer separations. A stimulus-averaging account, however, would predict a fixed amount of deviation based on the change in object size. Furthermore, a stimulus-averaging account would help to explain the bias to judge separations "farther" than "closer" when size and distance remained changed. To better determine whether participants were biased to judge objects from their centres of mass (i.e., stimulus averaging), a further study should be completed in which task instructions are to judge stimuli from their centres of mass. If the bias to respond "farther" more than "closer" is still present in the trials where size and separation remain unchanged, then it is likely that participants were biased to judge separations from objects' centres of mass. For this interpretation to be accurate, this bias to judge from the centres of mass must be stronger in the representation of the source image than the target image (essentially lengthening the separation in the source image).

SUMMARY

The present research investigated the influence of object size on judgments of lateral separation. Prior research has argued that visual angle is the predominant cue in exocentric distance perception (Levin & Haber, 1993; Matsushima et al., 2005). Under this visual angle prediction, changes in object size should not influence judgments of lateral separation. Studies of size cues on judgments of relative depth, however, have shown a varied but significant influence of object size across various task instructions (Epstein, 1963; i.e., objective or apparent) and methodological implementations (Carlson & Tassone, 1971; Park & Michaelson, 1974; Mershon & Gogel, 1975). Assuming judgments of depth and separation subsume similar processes, it is likely that object size should influence judgments of separation. Gogel and Da Silva (1987a) presented evidence that direct judgments of distance could be dissociated from the indirect perception of distance, which lead to their theorizing a two-process *theory of off-sized perceptions*. The theory of off-sized perceptions predicts that changes in object size should affect inter-object distance judgments. A one-shot change detection methodology (Phillips, 1974; Cole et al., 2003) was adopted to examine the role of object size judgments of lateral separation. Four experiments identified that changes in object size affect both the judgment and reproduction of both separation (Experiments 1 to 3) and line length magnitudes (Experiment 4) consistent with the predictions of the theory of off-sized perceptions.

Experiment 1 used a three-alternative forced-choice "closer-same-farther" paradigm to examine the influence of object size on judgments of lateral separation. Changes in object size significantly influenced participants' judgment of separation

consistent with the predictions of the theory of off-sized perceptions. In particular, when object size increased, participants underestimated the separation between the objects. Conversely, when object size decreased, participants overestimated the separation between the objects. Response times were significantly longer in trials where object size changed, implying that participants were processing this change. Furthermore, trials with correct responses were responded to quicker than trials with incorrect responses, implying that some cue conflict occurred. In addition, participants were three times as likely to judge the distance "farther" than "closer" in trials where neither size nor distance was changed. This was attributed to an attentional feedback hypothesis, where participants' attention was biased towards a resting state during the pattern mask. Finally, when size and distance changed in proportion, participants were biased to judge the distance unchanged, suggesting that participants were rapidly adopting a heuristic comparing object size to separation (referred to as generating an ad-hoc metric).

Experiment 2 extended the design of the one-shot change detection task requiring a distance reproduction response using the mouse. This response provided more evidence as to the quantitative changes in distance judgments due to changes in object size. While changes in object size significantly influenced distance reproductions, the deviations in distance were only 13% to 20% of those expected from familiar size cues. This partial dragging deviation was likely due to conflict between familiar size cues and the separation specified by visual angle, and was consistent with the small yet significant effect of familiar size cues on egocentric depth judgments (Gogel, 1981; Gogel & Mertens, 1968; Mershon & Gogel, 1975). Furthermore, participants were also biased to overestimate relatively closer separations and underestimate relatively farther separations. This deviation due to different initial separations was consistent with the predictions of the attentional feedback hypothesis.

Experiment 3 replicated the forced-choice response from Experiment 1, but extended the design to include varied pattern mask durations and the inclusion of two interference tasks. The central results of Experiment 1 were replicated; object size significantly influenced distance judgments. The pattern mask condition identified that longer mask durations increased bias to judge the separation "farther" rather than "closer" when object size and separation remained unchanged. The results of the 300 ms pattern mask trials, however, were inconsistent with the predictions of the attentional feedback hypothesis. Attention should not shift at mask durations less than 500 ms, thus, there should have been no farther-bias at the 300 ms mask duration. In addition, the interference tasks suggested that it was possible to load up memory such that size cues were less effective in distance judgments. Unfortunately, the effect of the interference task was marginal. In addition, longer pattern mask durations appear to have subsumed the effect of the interference task. Again, similar to Experiment 1, RTs were increased when size cues conflicted with separation (i.e., size-change and congruent-change trials).

Finally, Experiment 4 adopted line magnitude estimation and line production tasks, whose results suggested that judgments of lateral separation were processed similar to judgments of perceived size (i.e., line lengths). In particular, line length judgments were affected by changes in object size despite task instructions to rely on object size in the source image. Furthermore, object size was systematically overestimated in both the line magnitude estimation and line production tasks. When this overestimation was taken into account, participants were extremely accurate in using object-size as a metric consistent with the ad-hoc metrics heuristic.

In conclusion, the current research has shown that object size significantly influences judgments of lateral separation. This influence of object size has been shown using a forced-choice distance judgment task (Experiments 1 and 3), a distance reproduction task (Experiment 2), and a line magnitude estimation task (Experiment 4). These converging results support the extension of the theory of off-sized perceptions to judgments of exocentric distance.

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APPENDIX A: LIST OF DESCRIPTIVE STATISTICS

Table 5

Mean RTs and Accuracy in Experiment 1 by Change Type (No-Change, Distance-Change, Size-Change, or Congruent), Initial Distance (2, 3, or 4 Objects-Apart), and Orientation (Horizontal or Vertical).

			No Change		***Distance***		***Size***		***Distance and Size***	
RT	VERT	2	1212	(61)	1175	(58)	1347	(53)	1436	(54)
		3	1216	(58)	1244	(61)	1413	(60)	1491	(52)
		4	1237	(64)	1271	(51)	1335	(54)	1466	(64)
	HORIZ	2	1271	(87)	1136	(41)	1390	(60)	1338	(48)
		3	1223	(72)	1190	(49)	1432	(61)	1401	(59)
		4	1373	(84)	1209	(54)	1506	(76)	1377	(54)
	M	**2**	**1241**	**(64)**	**1155**	**(42)**	**1369**	**(50)**	**1387**	**(41)**
		3	**1220**	**(59)**	**1217**	**(48)**	**1423**	**(55)**	**1447**	**(50)**
		4	**1305**	**(65)**	**1240**	**(42)**	**1420**	**(57)**	**1422**	**(51)**
		M	***1256***	***(49)***	***1205***	***(38)***	***1404***	***(48)***	***1419***	***(44)***
ACC	VERT	2	.816	(.041)	.885	(.036)	.664	(.033)	.402	(.034)
		3	.724	(.038)	.828	(.039)	.626	(.032)	.471	(.037)
		4	.661	(.041)	.736	(.045)	.518	(.046)	.575	(.032)
	HORIZ	2	.802	(.041)	.930	(.024)	.698	(.039)	.368	(.032)
		3	.805	(.039)	.851	(.039)	.626	(.036)	.463	(.031)
		4	.638	(.052)	.753	(.038)	.503	(.038)	.569	(.023)
	M	**2**	**.809**	**(.034)**	**.907**	**(.026)**	**.681**	**(.030)**	**.385**	**(.028)**
		3	**.764**	**(.032)**	**.839**	**(.034)**	**.626**	**(.030)**	**.467**	**(.029)**
		4	**.649**	**(.039)**	**.744**	**(.034)**	**.510**	**(.037)**	**.572**	**(.024)**
		M	***.741***	***(.027)***	***.830***	***(.029)***	***.606***	***(.029)***	***.475***	***(.024)***
SPLIT	**COR**		1197	(53)	1209	(38)	1357	(49)	1502	(54)
RTs	**INC**		1674	(100)	1361	(83)	1547	(64)	1400	(50)

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 6

Mean RTs and Accuracy (Deviation in Degrees of Visual Angle) in Experiment 2 by Change Type (.40° Object-Size Decrease, .20° Object-Size Decrease, No Change, .20° Object-Size Increase, .40° Object-Size Increase), Initial Distance (2, 3, or 4 Objects-Apart), and Orientation (Horizontal or Vertical).

			-.40°		*-.20°*		*No Change*		*+0.20°*		*+0.40°*	
RT	VER	2	2607	(208)	2400	(185)	2486	(226)	2520	(201)	2680	(265)
		3	2545	(219)	2646	(234)	2550	(219)	2849	(270)	2677	(247)
		4	3010	(334)	2841	(252)	3015	(376)	2761	(277)	2948	(322)
	HOR	2	2400	(185)	2652	(281)	2596	(236)	2486	(249)	2413	(167)
		3	2644	(206)	2602	(227)	2743	(249)	2657	(234)	2516	(172)
		4	2934	(263)	2971	(341)	2851	(280)	2901	(302)	2750	(254)
	M	**2**	**2504**	**(187)**	**2526**	**(222)**	**2541**	**(221)**	**2503**	**(204)**	**2546**	**(197)**
		3	**2595**	**(203)**	**2625**	**(224)**	**2646**	**(220)**	**2753**	**(247)**	**2596**	**(201)**
		4	**2973**	**(292)**	**2906**	**(283)**	**2933**	**(306)**	**2831**	**(272)**	**2849**	**(284)**
		M	***2960***	***(223)***	***2686***	***(234)***	***2707***	***(240)***	***2696***	***(234)***	***2664***	***(212)***
DEV	VER	2	.116	(.092)	.286	(.100)	.413	(.112)	.481	(.074)	.687	(.094)
		3	-.188	(.119)	-.083	(.113)	.088	(.114)	.249	(.130)	.333	(.121)
		4	-.520	(.182)	-.604	(.161)	-.320	(.152)	-.167	(.137)	-.001	(.205)
	HOR	2	.102	(.071)	.337	(.074)	.370	(.080)	.583	(.077)	.571	(.074)
		3	-.348	(.133)	-.038	(.122)	.086	(.110)	.123	(.114)	.177	(.092)
		4	-.669	(.175)	-.401	(.154)	-.328	(.133)	-.159	(.137)	-.133	(.159)
	M	**2**	**.109**	**(.076)**	**.312**	**(.077)**	**.391**	**(.086)**	**.532**	**(.070)**	**.629**	**(.071)**
		3	**-.268**	**(.118)**	**-.060**	**(.108)**	**.087**	**(.101)**	**.186**	**(.107)**	**.255**	**(.096)**
		4	**-.594**	**(.170)**	**-.503**	**(.151)**	**-.324**	**(.129)**	**-.163**	**(.126)**	**-.067**	**(.169)**
		M	***-.251***	***(.112)***	***-.084***	***(.103)***	***.052***	***(.089)***	***.185***	***(.092)***	***.272***	***(.100)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 7

Mean Accuracy in Experiment 3 Collapsed Across Tasks by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	.870	(.041)	.630	(.053)	.797	(.044)	.254	(.042)	.645	(.045)
	3	.754	(.064)	.659	(.049)	.783	(.040)	.297	(.043)	.623	(.048)
	4	.667	(.070)	.551	(.053)	.623	(.056)	.355	(.041)	.667	(.036)
600ms	2	.783	(.071)	.572	(.048)	.812	(.045)	.254	(.040)	.652	(.050)
	3	.667	(.073)	.623	(.059)	.674	(.046)	.283	(.037)	.696	(.033)
	4	.623	(.070)	.514	(.054)	.486	(.056)	.464	(.026)	.638	(.040)
1200ms	2	.754	(.048)	.594	(.057)	.754	(.052)	.319	(.046)	.688	(.047)
	3	.62	(.074)	.609	(.048)	.674	(.055)	.413	(.046)	.659	(.049)
	4	.362	(.063)	.391	(.054)	.420	(.052)	.420	(.033)	.688	(.034)
2400ms	2	.667	(.051)	.543	(.055)	.681	(.064)	.384	(.032)	.601	(.040)
	3	.565	(.064)	.580	(.048)	.580	(.050)	.348	(.047)	.630	(.043)
	4	.319	(.068)	.420	(.063)	.370	(.054)	.486	(.039)	.696	(.034)
M	**2**	**.768**	**(.035)**	**.585**	**(.038)**	**.761**	**(.042)**	**.303**	**(.028)**	**.647**	**(.033)**
	3	**.659**	**(.057)**	**.618**	**(.036)**	**.678**	**(.040)**	**.335**	**(.029)**	**.652**	**(.033)**
	4	**.493**	**(.046)**	**.469**	**(.048)**	**.475**	**(.047)**	**.431**	**(.025)**	**.672**	**(.025)**
	M	***.640***	***(.039)***	***.557***	***(.037)***	***.638***	***(.037)***	***.356***	***(.023)***	***.657***	***(.026)***

Note. Values enclosed in parentheses represent standard error.

Table 8

Mean Accuracy in Experiment 3 for Standard Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	.870	(.072)	.609	(.083)	.783	(.061)	.283	(.069)	.652	(.066)
	3	.826	(.081)	.587	(.081)	.652	(.073)	.239	(.053)	.565	(.057)
	4	.522	(.106)	.500	(.070)	.609	(.083)	.348	(.066)	.652	(.058)
600ms	2	.870	(.072)	.543	(.070)	.739	(.076)	.261	(.062)	.674	(.060)
	3	.652	(.102)	.783	(.076)	.674	(.074)	.304	(.052)	.717	(.053)
	4	.739	(.094)	.522	(.067)	.500	(.070)	.413	(.060)	.674	(.060)
1200ms	2	.826	(.081)	.543	(.076)	.783	(.069)	.348	(.066)	.761	(.053)
	3	.696	(.098)	.674	(.060)	.783	(.061)	.457	(.070)	.717	(.069)
	4	.261	(.094)	.326	(.074)	.435	(.085)	.478	(.038)	.717	(.053)
2400ms	2	.609	(.104)	.435	(.072)	.543	(.076)	.391	(.077)	.587	(.040)
	3	.522	(.106)	.652	(.076)	.587	(.068)	.457	(.076)	.761	(.062)
	4	.217	(.088)	.413	(.063)	.413	(.075)	.500	(.063)	.696	(.052)
M	**2**	**.793**	**(.052)**	**.533**	**(.045)**	**.712**	**(.052)**	**.321**	**(.039)**	**.668**	**(.029)**
	3	**.674**	**(.078)**	**.674**	**(.045)**	**.674**	**(.040)**	**.364**	**(.036)**	**.690**	**(.046)**
	4	**.435**	**(.059)**	**.440**	**(.057)**	**.489**	**(.055)**	**.435**	**(.029)**	**.685**	**(.033)**
	M	***.634***	***(.039)***	***.549***	***(.043)***	***.625***	***(.037)***	***.373***	***(.024)***	***.681***	***(.024)***

Note. Values enclosed in parentheses represent standard error.

Table 9

Mean Accuracy in Experiment 3 for Imagery Interference Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	.870	(.072)	.565	(.091)	.804	(.061)	.196	(.052)	.603	(.065)
	3	.696	(.098)	.717	(.069)	.804	(.061)	.370	(.056)	.630	(.078)
	4	.696	(.098)	.587	(.081)	.609	(.063)	.435	(.065)	.609	(.073)
600ms	2	.696	(.098)	.565	(.065)	.804	(.075)	.261	(.053)	.717	(.069)
	3	.696	(.098)	.565	(.072)	.630	(.084)	.283	(.061)	.630	(.065)
	4	.435	(.106)	.457	(.083)	.457	(.070)	.543	(.043)	.609	(.070)
1200ms	2	.739	(.094)	.565	(.072)	.674	(.081)	.391	(.077)	.717	(.061)
	3	.565	(.106)	.522	(.074)	.609	(.083)	.391	(.063)	.630	(.078)
	4	.348	(.102)	.391	(.077)	.413	(.075)	.457	(.054)	.717	(.053)
2400ms	2	.609	(.104)	.522	(.074)	.739	(.082)	.435	(.072)	.652	(.049)
	3	.565	(.106)	.609	(.077)	.587	(.081)	.261	(.062)	.543	(.062)
	4	.435	(.106)	.457	(.088)	.326	(.074)	.435	(.065)	.652	(.054)
M	**2**	**.728**	**(.052)**	**.554**	**(.045)**	**.755**	**(.052)**	**.321**	**(.036)**	**.679**	**(.041)**
	3	**.630**	**(.078)**	**.603**	**(.045)**	**.658**	**(.060)**	**.326**	**(.034)**	**.609**	**(.049)**
	4	**.478**	**(.059)**	**.473**	**(.057)**	**.451**	**(.047)**	**.647**	**(.034)**	**.647**	**(.037)**
	M	***.612***	***(.046)***	***.543***	***(.039)***	***.621***	***(.042)***	***.371***	***(.025)***	***.645***	***(.032)***

Note. Values enclosed in parentheses represent standard error.

Table 10

Mean Accuracy in Experiment 3 for Phonological Interference Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	.870	(.072)	.717	(.069)	.804	(.075)	.283	(.061)	.652	(.066)
	3	.739	(.094)	.674	(.067)	.891	(.044)	.283	(.069)	.674	(.081)
	4	.783	(.088)	.565	(.079)	.652	(.073)	.283	(.069)	.696	(.068)
600ms	2	.783	(.088)	.609	(.077)	.891	(.044)	.239	(.076)	.565	(.079)
	3	.652	(.102)	.522	(.080)	.717	(.069)	.261	(.062)	.739	(.069)
	4	.696	(.098)	.565	(.079)	.500	(.083)	.435	(.065)	.630	(.056)
1200ms	2	.696	(.098)	.674	(.074)	.804	(.061)	.217	(.061)	.587	(.081)
	3	.696	(.098)	.630	(.072)	.630	(.078)	.391	(.070)	.630	(.065)
	4	.478	(.106)	.457	(.070)	.413	(.081)	.326	(.067)	.360	(.074)
2400ms	2	.783	(.088)	.674	(.067)	.761	(.076)	.326	(.051)	.565	(.079)
	3	.609	(.104)	.478	(.086)	.565	(.079)	.326	(.074)	.587	(.068)
	4	.304	(.098)	.391	(.077)	.370	(.078)	.522	(.049)	.783	(.053)
M	**2**	**.783**	**(.053)**	**.668**	**(.045)**	**.815**	**(.045)**	**.266**	**(.039)**	**.592**	**(.053)**
	3	**.674**	**(.071)**	**.576**	**(.049)**	**.701**	**(.041)**	**.315**	**(.047)**	**.658**	**(.051)**
	4	**.565**	**(.067)**	**.495**	**(.051)**	**.484**	**(.060)**	**.391**	**(.039)**	**.685**	**(.037)**
	M	***.674***	***(.048)***	***.580***	***(.041)***	***.667***	***(.043)***	***.324***	***(.031)***	***.645***	***(.038)***

Note. Values enclosed in parentheses represent standard error.

Table 11

Mean RTs in Experiment 3 by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	967	(74)	1159	(133)	1141	(106)	1195	(93)	1095	(70)
	3	1167	(118)	1319	(116)	1243	(113)	1326	(146)	1162	(117)
	4	1275	(125)	1277	(131)	1274	(124)	1271	(106)	1135	(71)
600ms	2	1026	(98)	1161	(117)	1037	(76)	1231	(111)	1117	(53)
	3	1131	(131)	1207	(116)	1118	(101)	1308	(101)	1169	(100)
	4	1130	(89)	1169	(83)	1085	(94)	1221	(83)	1152	(101)
1200ms	2	1130	(90)	1144	(98)	1220	(136)	1276	(120)	1193	(122)
	3	1260	(154)	1249	(100)	1235	(111)	1362	(157)	1189	(105)
	4	1294	(109)	1232	(100)	1171	(82)	1237	(108)	1181	(107)
2400ms	2	1178	(97)	1255	(95)	1167	(91)	1314	(96)	1144	(84)
	3	1340	(126)	1268	(105)	1132	(70)	1260	(89)	1367	(148)
	4	1350	(107)	1285	(107)	1315	(88)	1237	(68)	1215	(92)
M	**2**	**1075**	**(62)**	**1180**	**(89)**	**1141**	**(83)**	**1254**	**(86)**	**1137**	**(83)**
	3	**1225**	**(91)**	**1261**	**(93)**	**1182**	**(84)**	**1314**	**(88)**	**1222**	**(97)**
	4	**1262**	**(87)**	**1241**	**(93)**	**1211**	**(81)**	**1228**	**(75)**	**1171**	**(79)**
	M	***1188***	***(70)***	***1227***	***(88)***	***1178***	***(79)***	***1265***	***(78)***	***1177***	***(80)***
RTCOR	2	1026	(65)	1145	(92)	1091	(78)	1402	(89)	1154	(79)
	3	1117	(78)	1260	(114)	1098	(68)	1397	(102)	1139	(64)
	4	1206	(96)	1298	(98)	1213	(116)	1152	(81)	1092	(71)
	M	**1116**	**(68)**	**1234**	**(91)**	**1134**	**(74)**	**1317**	**(82)**	**1128**	**(67)**
RTINC	2	1272	(72)	1340	(118)	1457	(166)	1192	(86)	1167	(119)
	3	1518	(118)	1351	(89)	1342	(109)	1310	(122)	1492	(204)
	4	1378	(108)	1311	(130)	1324	(115)	1271	(84)	1249	(83)
	M	**1389**	**(81)**	**1334**	**(103)**	**1374**	**(112)**	**1257**	**(89)**	**1303**	**(119)**

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 12

Mean RTs in Experiment 3 for Standard Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	846	(66)	1061	(97)	1121	(151)	1108	(122)	999	(79)
	3	1028	(179)	1420	(163)	1446	(191)	1274	(181)	1179	(140)
	4	1231	(192)	1409	(246)	1337	(161)	1414	(254)	1056	(85)
600ms	2	865	(64)	1192	(182)	1037	(134)	995	(72)	1088	(72)
	3	1028	(179)	1270	(186)	1092	(93)	1234	(127)	1377	(162)
	4	1231	(155)	1037	(89)	1048	(156)	1155	(95)	1141	(131)
1200ms	2	963	(105)	1134	(143)	1088	(189)	1227	(194)	1004	(89)
	3	1459	(446)	1161	(112)	1316	(224)	1148	(102)	1251	(141)
	4	1010	(92)	1235	(131)	1177	(189)	1105	(78)	1155	(114)
2400ms	2	1284	(246)	1348	(137)	1200	(135)	1352	(172)	1114	(115)
	3	1044	(92)	1289	(127)	1311	(223)	1138	(119)	1048	(52)
	4	1097	(135)	1161	(112)	1107	(115)	1265	(138)	1188	(125)
M	**2**	**959**	**(63)**	**1132**	**(108)**	**1111**	**(104)**	**1163**	**(88)**	**1056**	**(70)**
	3	**1265**	**(144)**	**1281**	**(116)**	**1232**	**(121)**	**1235**	**(95)**	**1273**	**(105)**
	4	**1436**	**(147)**	**1278**	**(118)**	**1228**	**(115)**	**1247**	**(100)**	**1165**	**(112)**
	M	***1220***	***(92)***	***1230***	***(95)***	***1191***	***(105)***	***1215***	***(84)***	***1165***	***(86)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 13

Mean RTs in Experiment 3 for Imagery Interference Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	1010	(92)	1235	(131)	1177	(189)	1105	(78)	1155	(114)
	3	1284	(246)	1348	(137)	1200	(135)	1352	(172)	1114	(115)
	4	1044	(92)	1289	(127)	1311	(223)	1138	(119)	1048	(52)
600ms	2	1097	(135)	1161	(112)	1107	(115)	1265	(138)	1188	(125)
	3	1117	(133)	1148	(111)	1151	(160)	1303	(110)	1107	(109)
	4	1132	(80)	1301	(152)	1226	(119)	1201	(93)	1311	(152)
1200ms	2	1328	(178)	1251	(151)	1392	(199)	1250	(132)	1289	(178)
	3	1298	(164)	1315	(123)	1199	(85)	1436	(235)	1109	(104)
	4	1233	(123)	1158	(137)	1227	(117)	1126	(96)	1119	(89)
2400ms	2	1355	(260)	1434	(131)	1135	(114)	1185	(112)	1086	(109)
	3	1222	(151)	1330	(155)	1153	(93)	1330	(160)	1170	(100)
	4	1232	(112)	1263	(137)	1259	(103)	1255	(98)	1183	(94)
M	**2**	**1198**	**(102)**	**1270**	**(99)**	**1203**	**(110)**	**1201**	**(89)**	**1180**	**(97)**
	3	**1230**	**(117)**	**1286**	**(94)**	**1176**	**(82)**	**1355**	**(106)**	**1125**	**(74)**
	4	**1160**	**(58)**	**1253**	**(113)**	**1256**	**(115)**	**1180**	**(72)**	**1165**	**(81)**
	M	***1196***	***(73)***	***1270***	***(95)***	***1211***	***(89)***	***1246***	***(82)***	***1157***	***(75)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 14

Mean RTs in Experiment 3 for Phonological Interference Task by Change Type (No-Change, Distance-Change, Size-Change, Congruent-Change, and Incongruent-Change), Initial Distance (2, 3, or 4 Objects-Apart), and Pattern Mask Duration (300 ms, 600 ms, 1200 ms, and 2400 ms).

		No-Change		***Size-Change***		***Distance Change***		***Congruent Change***		***Incongruent Change***	
300ms	2	1117	(133)	1148	(111)	1151	(160)	1303	(110)	1107	(109)
	3	1132	(80)	1301	(152)	1226	(119)	1201	(93)	1311	(152)
	4	1328	(178)	1251	(151)	1392	(199)	1250	(132)	1289	(178)
600ms	2	1298	(164)	1315	(123)	1199	(85)	1436	(235)	1109	(104)
	3	1233	(123)	1158	(137)	1227	(117)	1126	(96)	1119	(89)
	4	1355	(260)	1434	(131)	1135	(114)	1185	(112)	1086	(109)
1200ms	2	1222	(151)	1330	(155)	1153	(93)	1330	(160)	1170	(100)
	3	1232	(112)	1263	(137)	1259	(103)	1255	(98)	1183	(94)
	4	846	(66)	1061	(97)	1121	(151)	1108	(122)	999	(79)
2400ms	2	1151	(179)	1420	(162)	1446	(191)	1274	(181)	1179	(140)
	3	1359	(192)	1409	(246)	1337	(161)	1414	(254)	1056	(85)
	4	865	(64)	1192	(182)	1037	(134)	995	(72)	1088	(72)
M	**2**	**1069**	**(102)**	**1136**	**(115)**	**1109**	**(91)**	**1397**	**(131)**	**1177**	**(79)**
	3	**1179**	**(103)**	**1216**	**(106)**	**1137**	**(93)**	**1351**	**(105)**	**1267**	**(136)**
	4	**1190**	**(95)**	**1191**	**(87)**	**1150**	**(67)**	**1256**	**(83)**	**1182**	**(73)**
	M	***1146***	***(82)***	***1181***	***(93)***	***1132***	***(72)***	***1335***	***(91)***	***1208***	***(92)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 15

Mean RTs and Accuracy (Deviation in Degrees of Visual Angle) in Experiment 4 for Distance Production Task by Change Type (No-Object, No-Change, Size Decrease, and Size Increase) and Line Length (2-9 Objects Apart).

		No-Object		***No-Change***		***Size Decrease***		***Size Increase***		***M***	
ACC	2	.595	(.118)	.609	(.110)	.467	(.098)	.741	(.131)	.603	(.103)
	3	.787	(.164)	.728	(.145)	.481	(.143)	1.127	(.194)	.781	(.145)
	4	.932	(.242)	.981	(.233)	.622	(.231)	1.409	(.257)	.986	(.212)
	5	1.464	(.330)	1.239	(.276)	.578	(.262)	1.585	(.339)	1.216	(.270)
	6	1.507	(.406)	1.231	(.349)	.952	(.322)	1.335	(.505)	1.257	(.351)
	7	2.017	(.474)	1.880	(.432)	1.157	(.412)	1.716	(.436)	1.692	(.399)
	8	1.596	(.469)	1.626	(.529)	1.087	(.523)	1.778	(.585)	1.522	(.486)
	9	1.414	(.571)	1.639	(.594)	1.293	(.532)	2.410	(.541)	1.689	(.517)
	M	***1.289***	***(.312)***	***1.242***	***(.296)***	***.830***	***(.278)***	***1.513***	***(.324)***	***1.218***	***(.295)***
RT	2	711	(188)	929	(231)	936	(195)	875	(194)	862	(177)
	3	1167	(283)	1700	(346)	1609	(270)	1532	(297)	1502	(263)
	4	1396	(319)	2287	(443)	2125	(368)	2083	(336)	1972	(325)
	5	2264	(429)	2842	(476)	2540	(421)	2801	(517)	2611	(428)
	6	2419	(496)	3363	(533)	3244	(520)	3126	(529)	3038	(470)
	7	3094	(606)	3742	(601)	3613	(518)	3648	(495)	3524	(506)
	8	3224	(516)	3770	(623)	4031	(633)	4025	(726)	3763	(579)
	9	2969	(600)	3966	(704)	4707	(686)	4173	(701)	3954	(611)
	M	***2155***	***(418)***	***2825***	***(434)***	***2851***	***(407)***	***2783***	***(418)***	***2654***	***(404)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

Table 16

Mean Perceived Size in Experiment 4 for Distance Production Task by Initial Size (1.05°, 1.45°, 1.85°), Change Type (No-Object, No-Change, Size Decrease, and Size Increase) and Line Length (2-9 Objects Apart).

		No-Object		***No-Change***		***Size Decrease***		***Size Increase***		***M***	
ACC	2	1.427	(.072)	1.406	(.054)	1.411	(.063)	1.515	(.085)	1.440	(.055)
	3	1.495	(.083)	1.341	(.065)	1.295	(.079)	1.462	(.071)	1.398	(.060)
	4	1.442	(.062)	1.390	(.072)	1.294	(.069)	1.437	(.068)	.1391	(.057)
	5	1.551	(.097)	1.464	(.084)	1.380	(.048)	1.504	(.092)	1.475	(.065)
	6	1.584	(.097)	1.399	(.109)	1.424	(.066)	1.458	(.088)	1.466	(.067)
	7	1.609	(.096)	1.502	(.079)	1.404	(.071)	1.484	(.090)	1.500	(.067)
	8	1.463	(.105)	1.461	(.084)	1.423	(.081)	1.560	(.084)	1.477	(.071)
	9	1.468	(.904)	1.415	(.090)	1.419	(.108)	1.442	(.081)	1.438	(.078)
	M	***1.505***	***(.064)***	***1.422***	***(.062)***	***1.381***	***(.050)***	***1.483***	***(.066)***	***1.448***	***(.058)***
SID	2	1.843	(.118)	1.874	(.077)	1.742	(.063)	1.842	(.104)	1.826	(.068)
	3	1.765	(.066)	1.752	(.079)	1.621	(.064)	1.926	(.096)	1.766	(.065)
	4	1.769	(.098)	1.748	(.080)	1.712	(.103)	1.931	(.092)	.1790	(.072)
	5	1.881	(.106)	1.814	(.076)	1.669	(.063)	1.801	(.088)	1.792	(.064)
	6	1742	(.082)	1.773	(.074)	1.755	(.077)	1.869	(.012)	1.785	(.069)
	7	1.868	(.101)	1.782	(.079)	1.786	(.102)	1.707	(.114)	1.786	(.081)
	8	1.745	(.085)	1.706	(.084)	1.665	(.090)	1.752	(.098)	1.717	(.075)
	9	1.626	(.107)	1.718	(.100)	1.682	(.094)	1.738	(.111)	1.691	(.080)
	M	***1.780***	***(067.)***	***1.771***	***(.059)***	***1.704***	***(.061)***	***1.821***	***(.077)***	***1.769***	***(.062)***
RT	2	2.318	(.084)	2.247	(.076)	2.208	(.080)	2.329	(.111)	2.276	(.073)
	3	2.145	(.089)	2.244	(.074)	2.098	(.082)	2.309	(.116)	2.199	(.063)
	4	2.155	(.104)	2.201	(.078)	2.046	(.106)	2.348	(.099)	2.187	(.080)
	5	2.131	(.089)	2.112	(.077)	1.975	(.090)	2.198	(.108)	2.104	(.071)
	6	2.101	(.113)	2.065	(.094)	1.978	(.103)	2.082	(.110)	2.057	(.088)
	7	1.977	(.119)	2.112	(.115)	1.993	(.069)	2.141	(.117)	.2056	(.080)
	8	2.095	(.083)	2.114	(.117)	1.997	(.087)	2.110	(.117)	2.079	(.087)
	9	2.046	(.098)	2.108	(.099)	1.950	(.101)	2.173	(.083)	2.069	(.085)
	M	***2.121***	***(.073)***	***2.150***	***(.062)***	***2.031***	***(.070)***	***2.211***	***(.081)***	***2.128***	***(.067)***

Note. Values enclosed in parentheses represent standard error.

Table 17

Mean RTs, Accuracy (Proportion Correct), and Response Difference (Expected Response – Actual Response) in Experiment 4 for Distance Production Task by Change Type (No-Object, No-Change, Size Decrease, and Size Increase) and Line Length (2-9 Objects Apart).

		No-Object		***No-Change***		***Size Decrease***		***Size Increase***		***M***	
ACC	2	.744	(.051)	.750	(.066)	.827	(.048)	.786	(.057)	.777	(.041)
	3	.732	(.056)	.583	(.063)	.720	(.058)	.548	(.062)	.646	(.042)
	4	.446	(.054)	.440	(.062)	.542	(.062)	.405	(.060)	.458	(.041)
	5	.423	(.063)	.369	(.065)	.530	(.071)	.417	(.058)	.435	(.038)
	6	.345	(.047)	.238	(.054)	.268	(.044)	.250	(.058)	.275	(.032)
	7	.250	(.058)	.357	(.063)	.286	(.048)	.250	(.053)	.286	(.035)
	8	.262	(.052)	.208	(.053)	.262	(.052)	.238	(.059)	.243	(.038)
	M	***.457***	***(.028)***	***.421***	***(035.)***	***.491***	***(.032)***	***.413***	***(.030)***	***.446***	***(.024)***
DIF	2	-.077	(.078)	.060	(.081)	-.089	(.060)	-.024	(.079)	-.033	(.063)
	3	-.196	(.106)	.036	(.090)	-.125	(.098)	.155	(.106)	-.033	(.069)
	4	.054	(.127)	.274	(.120)	-.137	(.096)	.214	(.127)	.101	(.095)
	5	.220	(.134)	.345	(.127)	-.107	(.151)	.357	(.134)	.204	(.121)
	6	.381	(.151)	.51	(.159)	-.095	(.181)	.571	(.151)	.302	(.132)
	7	.625	(.163)	.690	(.179)	.155	(.187)	.893	(.163)	.591	(.143)
	8	.863	(.181)	.887	(.150)	.476	(.190)	1.131	(.181)	.839	(.145)
	M	***.267***	***(.108)***	***.378***	***(.107)***	***.011***	***(.110)***	***.471***	***(.104)***	***.282***	***(.101)***
RT	2	1885	(126)	2044	(169)	2050	(164)	2124	(132)	2026	(118)
	3	2135	(163)	2380	(169)	2476	(179)	2400	(200)	2348	(142)
	4	2463	(197)	3078	(318)	3215	(243)	2667	(176)	2856	(203)
	5	2912	(259)	3036	(244)	3379	(310)	3162	(290)	3123	(250)
	6	3207	(252)	3541	(381)	3444	(320)	3679	(322)	3468	(274)
	7	3226	(322)	3553	(346)	3965	(402)	3895	(331)	3660	(324)
	8	3505	(345)	3776	(429)	3508	(308)	3792	(366)	3645	(334)
	M	***2762***	***(201)***	***3058***	***(234)***	***3103***	***(222)***	***3148***	***(222)***	***3018***	***(216)***

Note. Values enclosed in parentheses represent standard error. RTs are in ms.

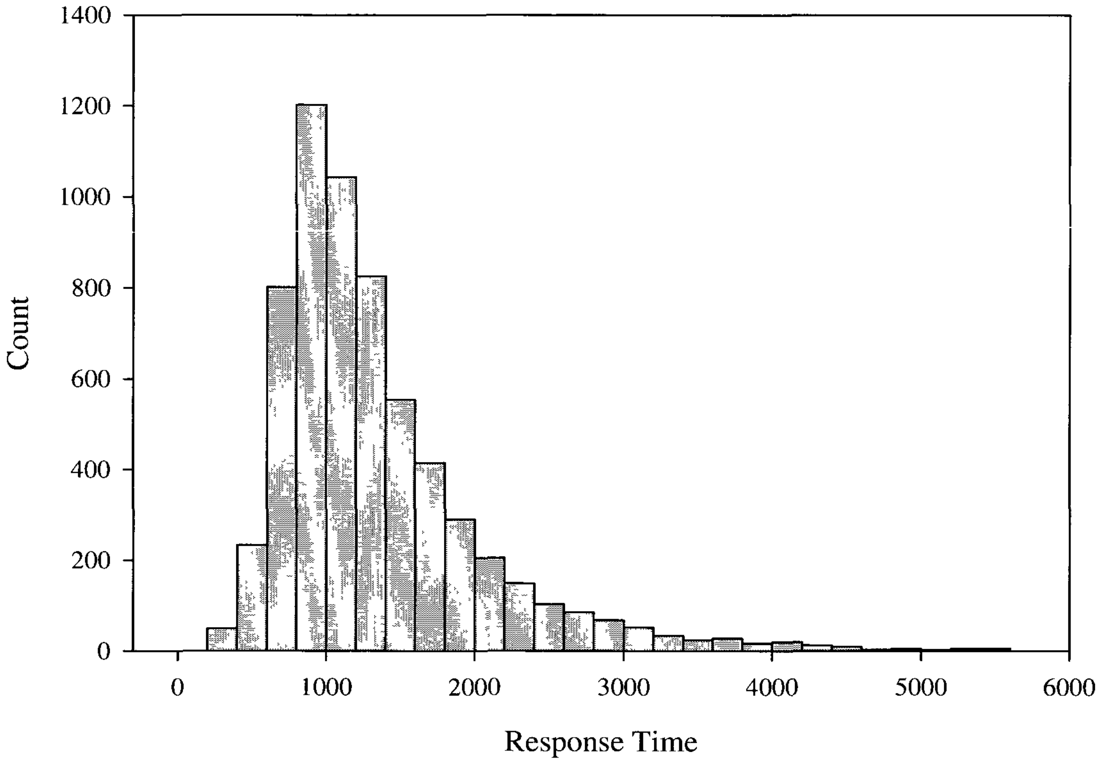


Figure 22. A histogram of response times for Experiment 1. The distribution has a skewness of 2.58 (SE = .03) and kurtosis of 12.00 (SE = .06).

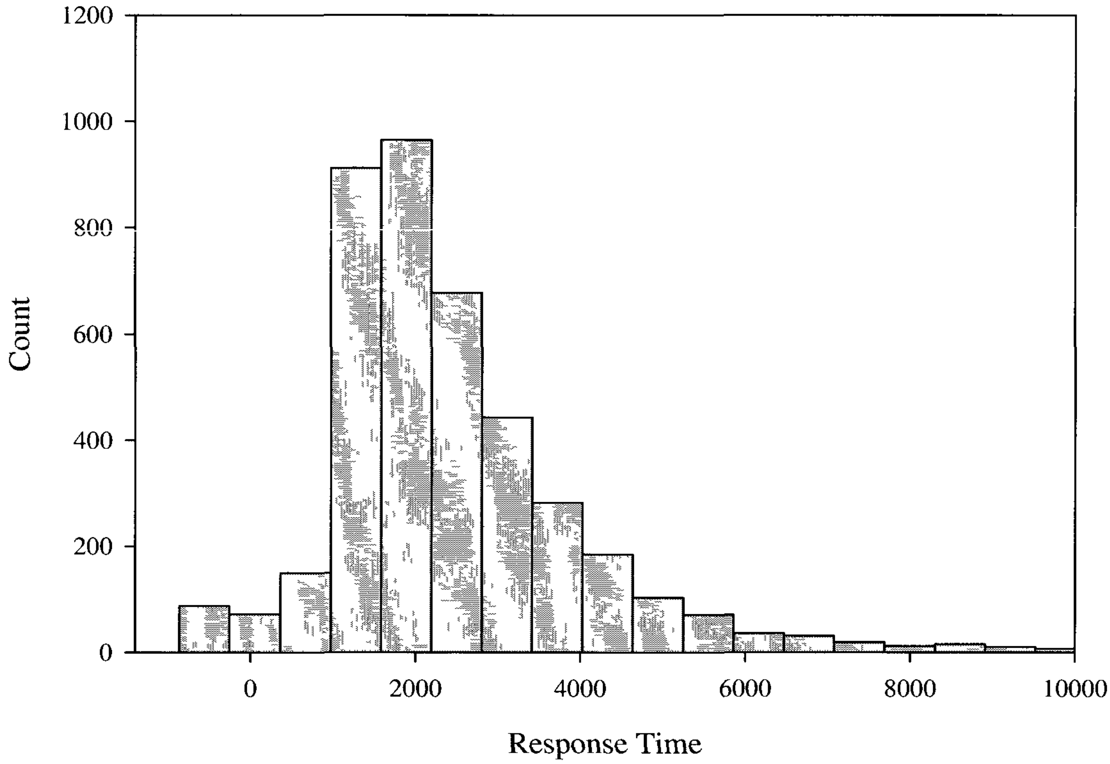


Figure 23. A histogram of response times for Experiment 2. The distribution has a skewness of .84 (SE = .13) and kurtosis of .57 (SE = .26).

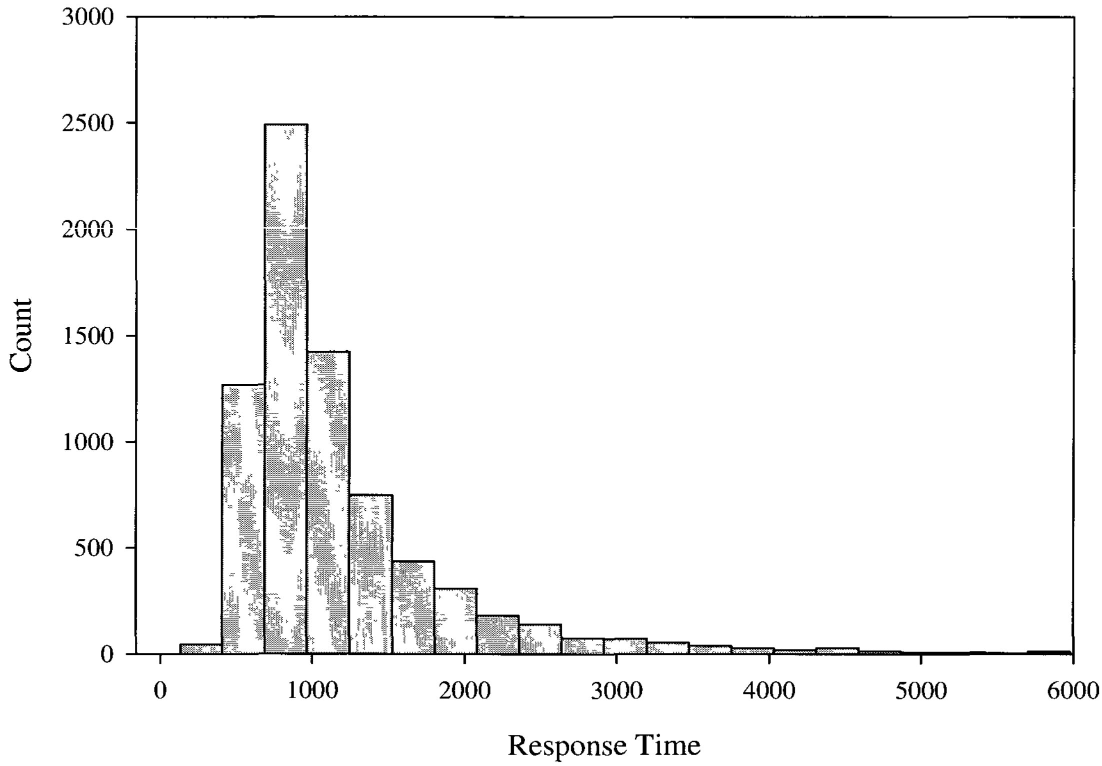


Figure 24. A histogram of response times for Experiment 3. The distribution has a skewness of 4.09 (SE = .03) and kurtosis of 29.78 (SE = .06).

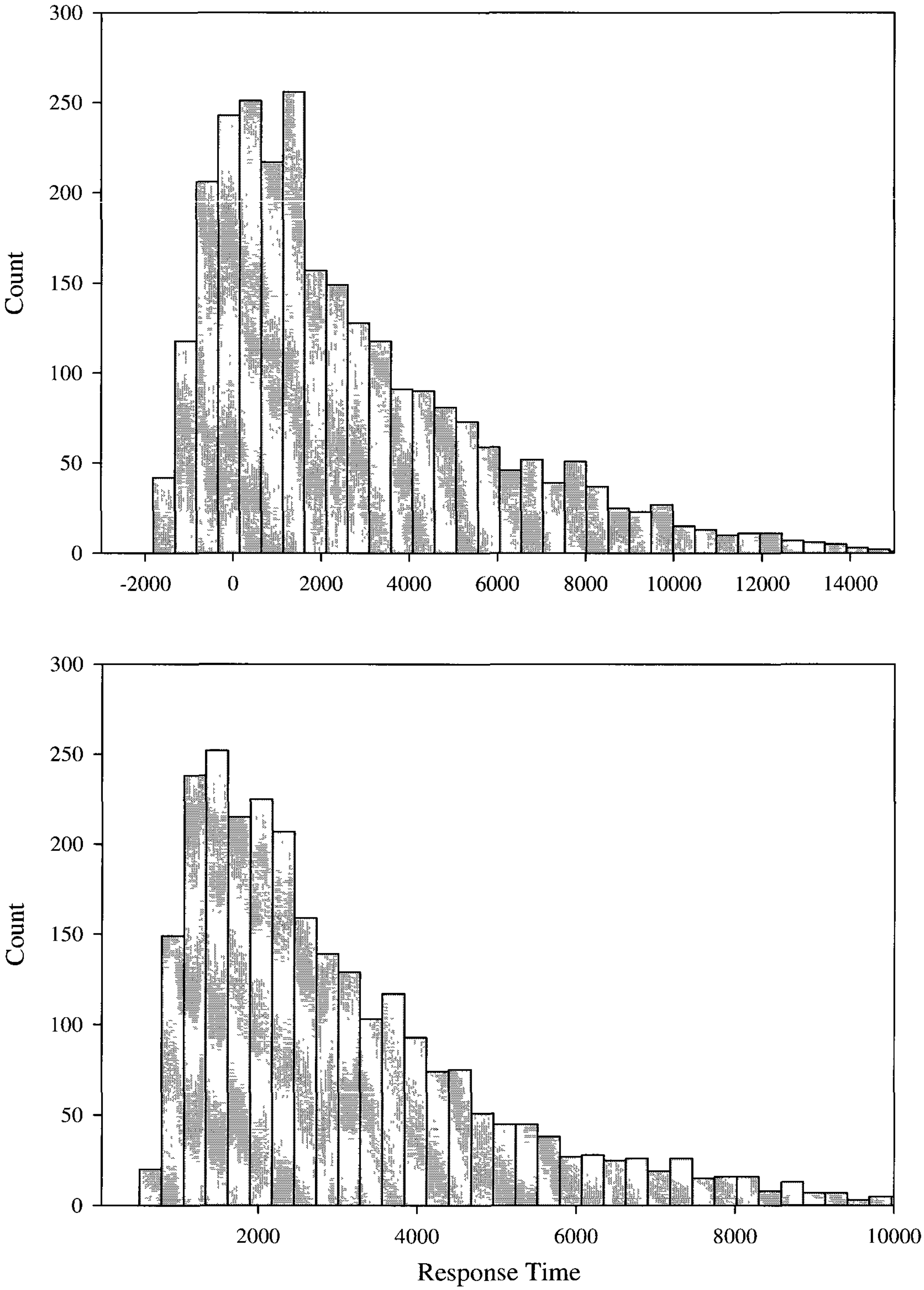


Figure 25. A histogram of response times for Experiment 4. The top panel is the distance production task (Fitts' adjusted) and bottom panel is the line length estimation task. The distribution of the distance production task has a skewness of -.43 (SE = .04) and a kurtosis of -.61 (SE = .09). The distribution of the line length estimation task has a skewness of 1.65 (SE = .05) and a kurtosis of 3.18 (SE = .09).

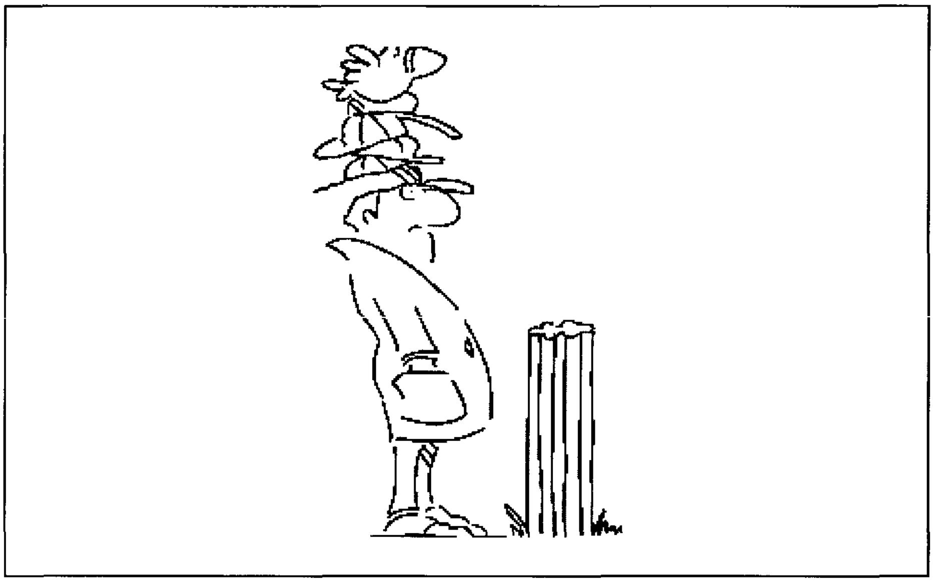
APPENDIX B: EXPERIMENT 3 INTERFERENCE CONDITION STIMULI

The 12 critical pseudo-words used in Experiment 3 are listed in the table below with their possible answers. After the pseudo-words, each of the 12 images used in Experiment 3 will be presented with the question asked and the possible forced-choice responses. For ease of viewing, the images shown to participants were white line drawings on a black background, but what is presented in these appendices are the same images with black lines on a white background.

Table 18

The List of CVCVs Used in Experiment 3. All Response 3s Are the Correct Response. Both CVCV and Response Order were Randomized Between Participants.

Critical CVCV	**Response 1**	**Response 2**	**Response 3**
CUYA	YURE	CEGA	CUYA
GEVI	ZAKI	GOPE	GEVI
KERO	NEYA	KUNA	KERO
MICU	FIPA	MARU	MICU
TOCE	LOZU	TOBA	TOCE
BOPA	ROFU	BAJE	BOPA
DAFE	BAJE	DOJA	DAFE
RIKO	VIPU	ROVA	RIKO
DUPA	NOHI	DAFO	DUPA
KUMI	XANI	KONU	KUMI
NOHA	DOJE	NAJI	NOHA
GACO	ZAME	GIRA	GACO



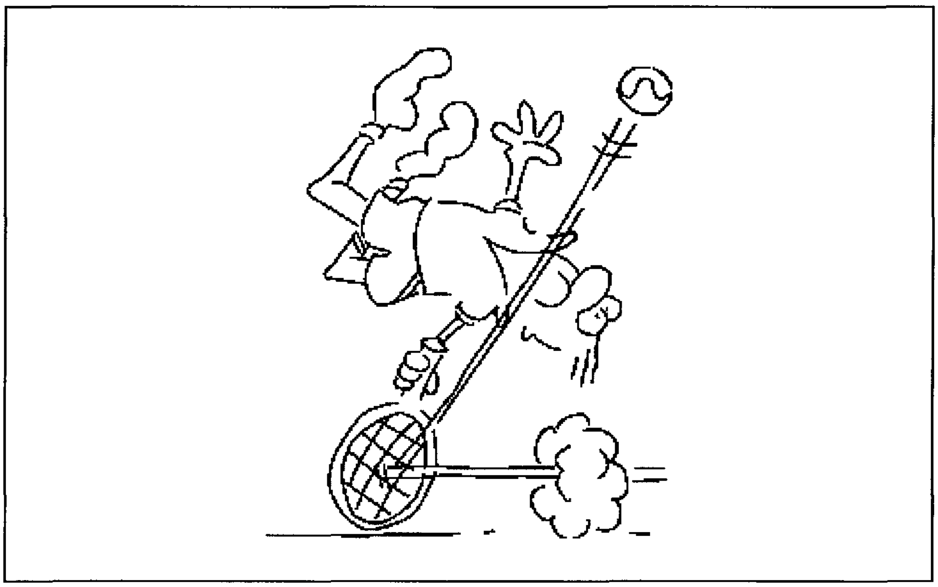
QUESTION: What is on the man's head?

CORRECT RESPONSE: A Bird

POSSIBLE RESPONSES: 1) A Flower

2) A Toque

3) A Bird



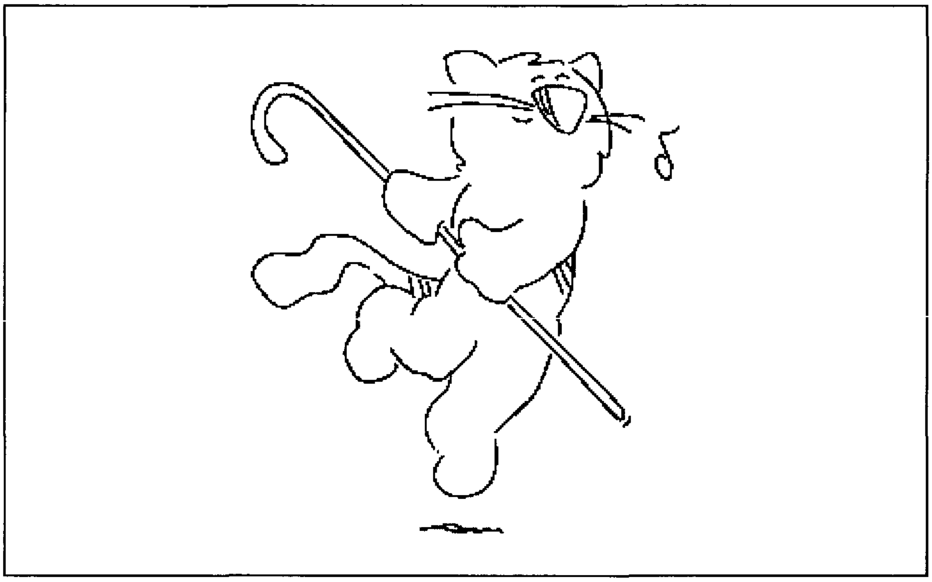
QUESTION: What sport is the man playing?

CORRECT RESPONSE: Tennis

POSSIBLE RESPONSES: 1) Badminton

2) Squash

3) Tennis



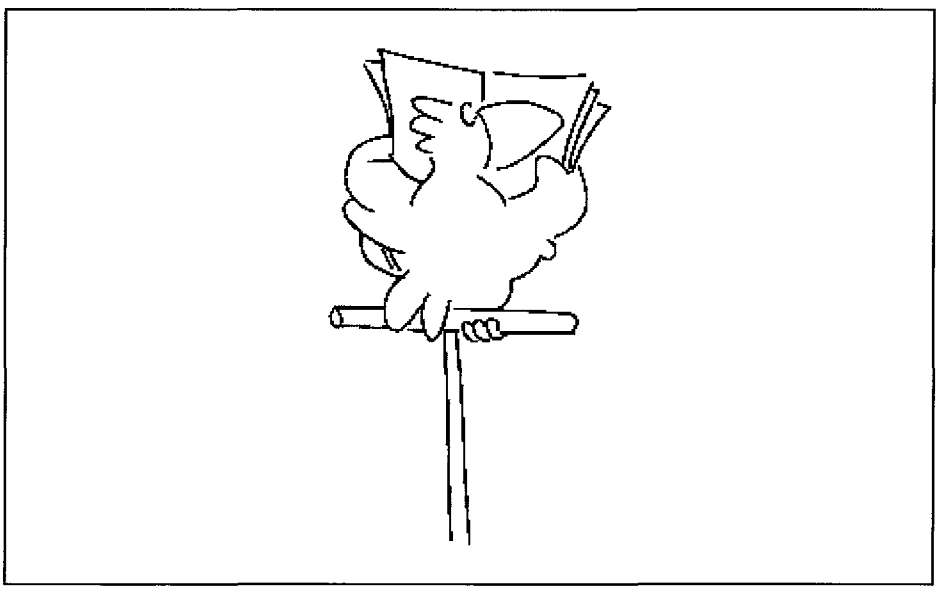
QUESTION: What is the cat holding in its paw?

CORRECT RESPONSE: A Cane

POSSIBLE RESPONSES: 1) A Fish

2) A Mouse

3) A Cane



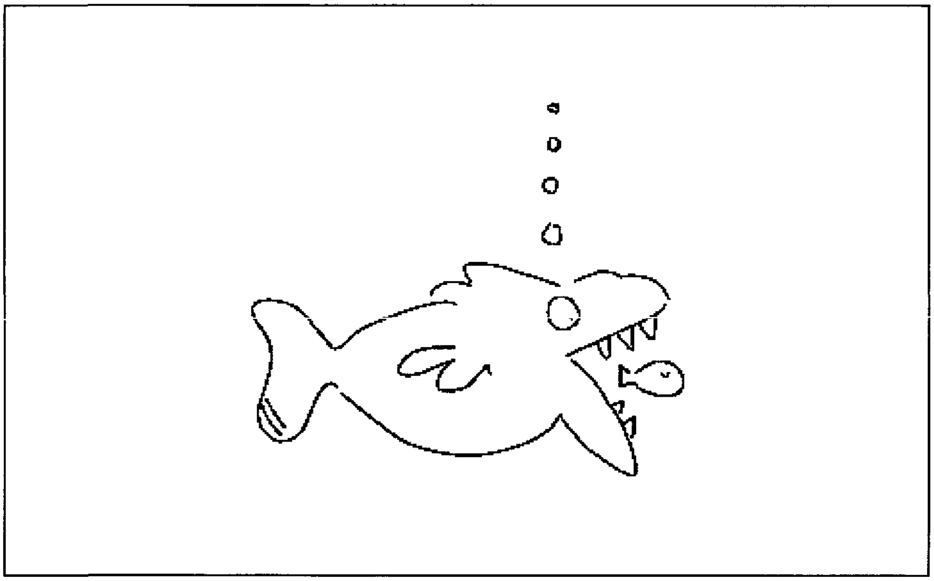
QUESTION: What is the bird doing?

CORRECT RESPONSE: Reading a Newspaper

POSSIBLE RESPONSES: 1) Singing a Song

2) Eating Birdseed

3) Reading a Newspaper



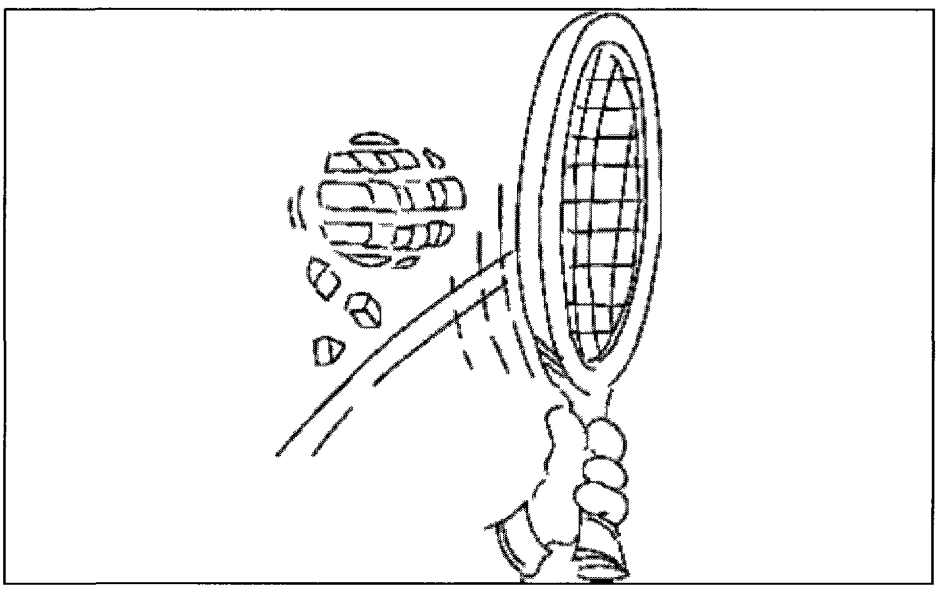
QUESTION: How many upper teeth does the big fish have?

CORRECT RESPONSE: Three

POSSIBLE RESPONSES: 1) Two

2) None

3) Three



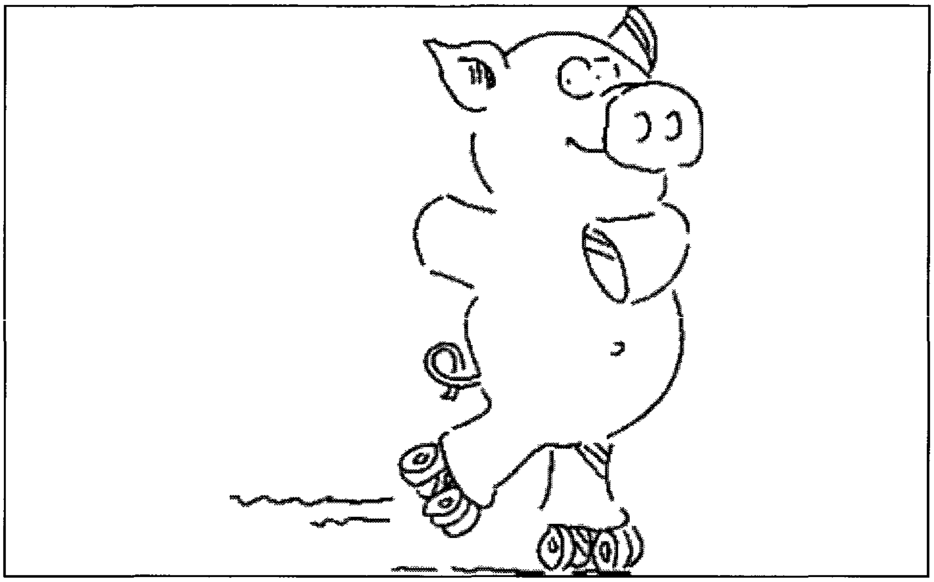
QUESTION: What happened to the ball when it hit the racket?

CORRECT RESPONSE: It Broke Apart

POSSIBLE RESPONSES: 1) It Fell Down

2) It Bounced Off

3) It Broke Apart



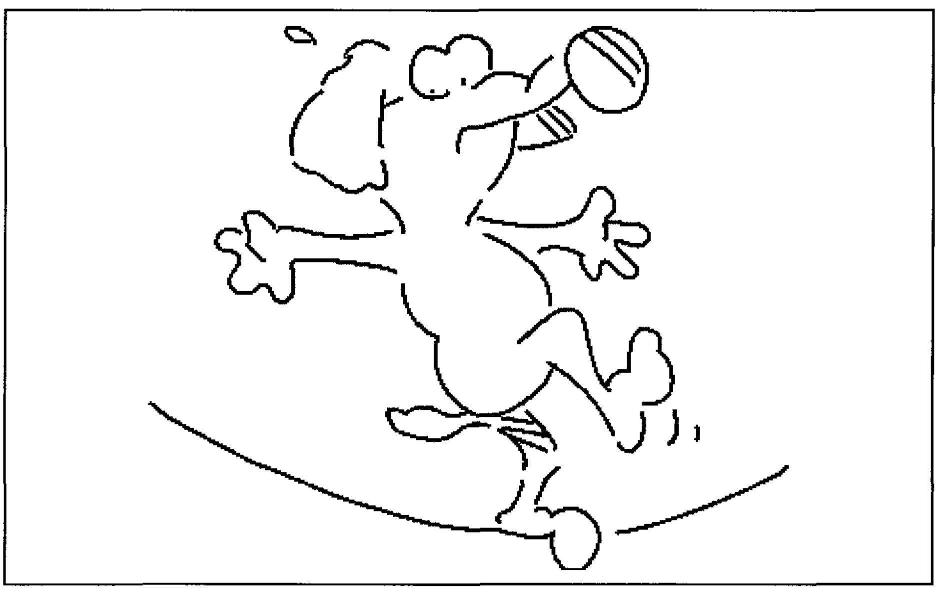
QUESTION: What is the pig doing?

CORRECT RESPONSE: Rollerblading

POSSIBLE RESPONSES: 1) Skating

2) Running

3) Rollerblading



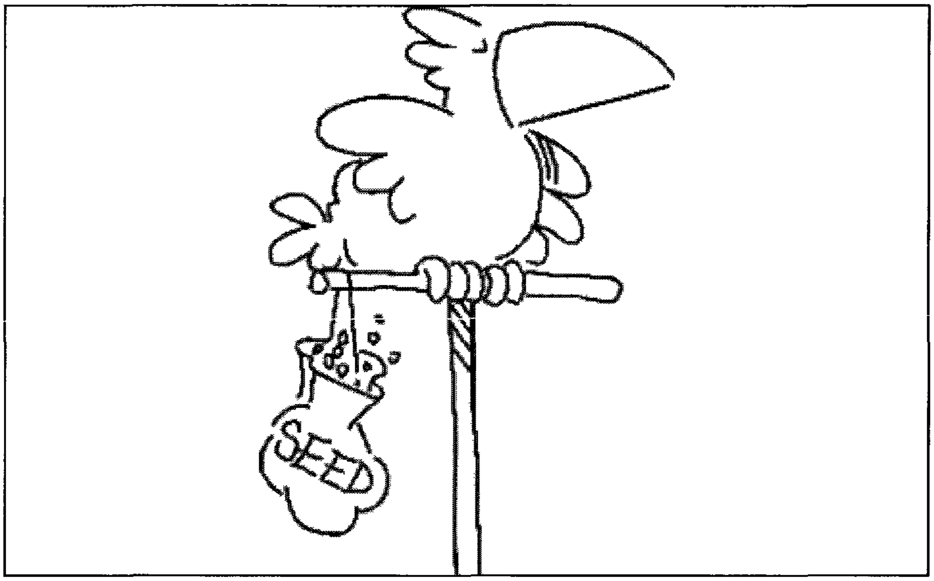
QUESTION: What is the dog doing?

CORRECT RESPONSE: Balancing

POSSIBLE RESPONSES: 1) Running

2) Swimming

3) Balancing



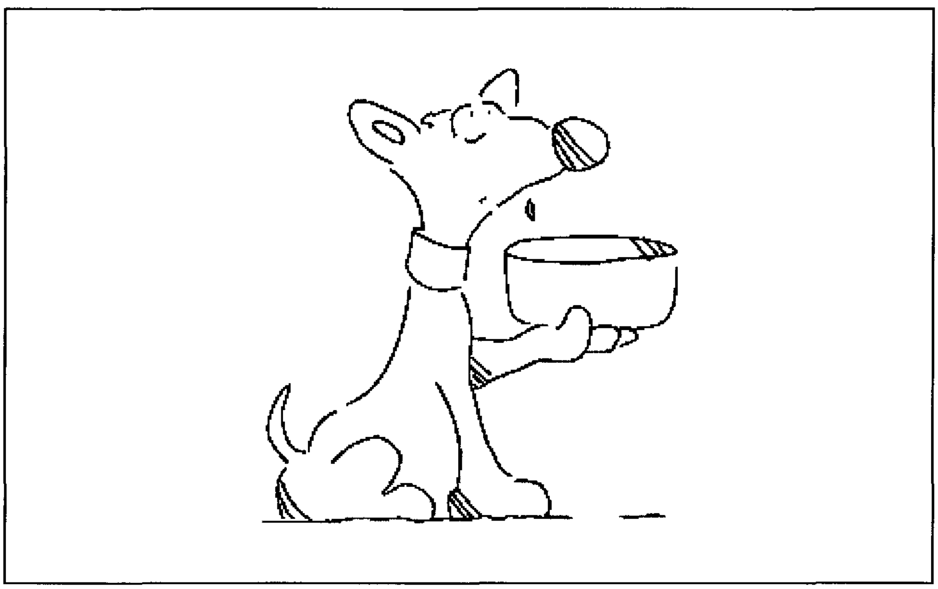
QUESTION: Where is the birdseed?

CORRECT RESPONSE: Beside the Bird

POSSIBLE RESPONSES: 1) Behind the Bird

2) In Front of the Bird

3) Beside the Bird



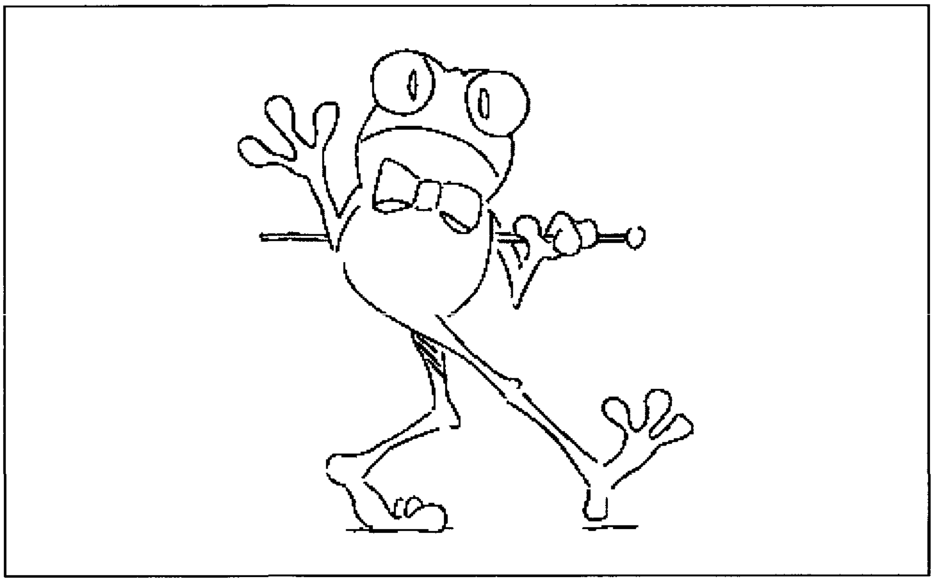
QUESTION: What is the dog holding in its paw?

CORRECT RESPONSE: A Food Dish

POSSIBLE RESPONSES: 1) A Ball

2) A Bone

3) A Food Dish



QUESTION: What is the frog wearing?

CORRECT RESPONSE: A Bowtie

POSSIBLE RESPONSES: 1) Pants

2) A Shirt

3) A Bowtie

QUESTION: What is on the woman's hat?

CORRECT RESPONSE: Fruit

POSSIBLE RESPONSES: 1) Umbrella

2) Flowers

3) Fruit