THESIS

CONFIGURAL ASYMMETRIES: AN EFFECT OF CONTEXT AND OBJECT BASED PROCESSES

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JOSHUA R. EDLER ENTITLED CONFIGURAL ASYMMETRIES: AN EFFECT OF CONTEXT AND OBJECT BASED PROCESSES BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

CONFIGURAL ASYMMETRIES: AN EFFECT OF CONTEXT AND OBJECT BASED PROCESSES

Configural asymmetries refer to differences in visual search performance in which displays composed of objects requiring left/right judgments, are slower to process and incur more errors than displays composed of objects requiring up/down judgments. Two accounts of the effect have emerged in the literature. The Object Region Account, an object-based explanation, posits configural asymmetries are driven by differences in processing the up/down versus left/right regions of an individual object, with left/right regions being less finely processed. The Inter-item Symmetry account, a context-based explanation, posits configural asymmetries are due to mirror symmetry relationships shared between multiple elements in the search display. Specifically, objects sharing vertical mirror symmetry are perceived as more similar and therefore harder to process than objects sharing horizontal mirror symmetry.

This study attempted to test and separate these two accounts. Measurements demonstrated that mirror symmetry relationships alone between target and distractors indeed produced an asymmetry in search performance – horizontal mirror symmetry was easier to search through than vertical mirror symmetry. Albeit the magnitude of the effect produced solely by mirror symmetry was noticeably smaller than the effect obtained

when objects required left/right versus up/down comparisons (e.g., Monnier, Atarha, Edler, & Birks, 2010; Van Zoest, Giesbrecht, Enns, Kingstone, 2006). Furthermore, when mirror symmetry was held between distractors the reverse effect was found – vertical mirror symmetry was easier to search through than horizontal mirror symmetry. These measurements support configural asymmetries are best understood as an interaction of both object-based and context-based processes and provide support that mirror symmetry is a dimension by which the visual system groups objects.

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VISUAL ATTENTION AND THE VISUAL SEARCH PARADIGM

Humans have the remarkable capacity to process a wide variety of visual information in a seemingly effortless manner, providing a stable and useful representation of the world. However, despite its sophistication, the visual system lacks the capacity to process all the possible information out in the environment. To compensate for this limited ability, incoming visual information is handled in two ways. First, the visual system naturally filters inputs depending on where the information falls on the retina. Acuity is highest at the fovea and gradually degrades in the periphery – a fact due to the peripheral retina containing ganglion cells with larger receptive field sizes and disproportionately less cortical area compared to the densely packed photoreceptors and cortical magnification of the fovea (Wilson, Levi, Maffei, Rovamo, & DeValois, 1990). Second, when environmental information exceeds the system's capacity, only a limited range of information is processed within the visual field. Attention acts as a guiding mechanism in this process, shifting the system's focus to various locations of interest within the search display in a serial fashion until search is terminated. An example of this serial processing of information is reading: attention shifts the eyes' focus from one word to the next with each word being analyzed individually by the visual system before the next word is processed. However, not all visual processes are limited to serial inspections. Some types of visual processes, termed *parallel processes*, are computed quickly and effortlessly across the entire visual field prior to the deployment of attention (Neisser, 1967).

Humans are relatively agnostic to the limitations of their visual system; limitations which appear paradoxical to the stability of the visual perceptions we experience daily. Moreover, most would be surprised to find not all information available in the environment is actually processed. Over the past two decades understanding these limitations of the visual system, how attention guides visual processing, and the attributes of the visual scene affecting processing have been central focuses of vision research. A popular paradigm used to address these issues of visual attention and processing efficiency is visual search (Wolfe, 1994). Visual search is a task we as humans are quite accustomed to and conduct daily. Finding a friend in the crowd, a book on a bookshelf, or a car in a parking lot are prime examples of visual searches. In a typical laboratory visual search task, participants are asked to search for some unique element referred to as the *target* among a given number of non-target elements termed *distractors*. Performance is measured by recording either the *accuracy* or *latency* of responses.

In an *accuracy* visual search task, the search display is briefly presented and the task is to decide whether a target element was present or absent during the presentation. On a random half of the trials a single target element is presented alongside a set number of distractors with the other random half of trials being displays composed of distractors only. Following the presentation, participants give forced choice responses indicating the absence/presence of a target while their accuracy is recorded. In a *latency* visual search task, the search display is presented until the participant makes a decision as to whether a target element is present in the display. Similar to the accuracy task, half the trials contain a *target* among distractors while the other half contains presentations of only distractors. Participants give forced choice responses indicating the absence/presence of a target and the time elapsed from the onset of the display until the signaling of the response is recorded.

The visual search paradigm not only provides a quantitative measure of search difficulty but can also provide information about how visual information is being processed and the underlying mechanisms governing search in the task. Manipulations of set size (the total number of elements presented together in the search display) are commonly employed to determine the efficiency of processing information and to indentify features. Features can be thought of as primitives of the visual system, a fundamental dimension of information processed independently by some elementary neural mechanism. Various studies have shown that attributes such as color, size, and motion are undoubted features which are encoded by independent mechanisms within the visual system and have the capacity to guide attention in search (Wolfe and Horowitz, 2004). These features are the "building blocks" underlying more complex representations of objects and whose identification has been critical to the visual search literature.

One way to identify these visual primitives is by interpreting set size functions (plots relating reaction time or accuracy as a function of set size). In general, flat set size functions such as slopes around 0-10 *ms*/item indicate fast, easy and efficient searches (Wolfe and Horowitz, 2004). Flat set size slopes suggest *parallel processing* of information: a search processed with seemingly endless resources where all elements are processed simultaneously. Additionally, flat set size functions suggest a search completed along a single feature or neural mechanism and are termed *feature searches*

(Rosenholtz, 2001). Steep set size functions (e.g., 20-60 *ms*/item), on the other hand, suggest *serial processing.* Serial processing occurs when the information presented exceeds the resources available to the visual system requiring attention to be deployed to guide search to areas of interest on the search display. These steep functions suggest searches requiring a conjunction of information across multiple features, involving the coordination between multiple neural mechanisms and are therefore termed *conjunction searches* (Rosenholtz, 2001).

PREDICTING SEARCH DIFFICULTY: ATTENTIONAL ENGAGEMENT THEORY

Visual search provides a quantitative measure of search difficulty and offers assumptions about the underlying mechanisms and processes sub-serving vision; two benefits that have made the paradigm useful over the past few decades. However, the visual search paradigm in itself does not offer a priori predictions as to what constitutes difficulty in visual search or offer an adequate model as to how the visual system handles incoming information. These predictions and modeling of visual processing have been central goals of theories of object perception. So what does constitute search difficulty?

It is clear from nearly a million visual search trials that difficulty is not adequately understood as a dichotomy between parallel and serial processing or corresponding feature and conjunction searches; rather, performance varies progressively between flat and steep set size functions (Wolfe, 1998). In addition to this continuum of search difficulty, there is doubt regarding the correspondence between parallel processing of feature searches and serial processing of conjunction searches. There is evidence showing that not all feature searches result in flat set size functions (Treisman & Gormican, 1988) nor do all conjunction searches result in steep set size functions (Enns & Rensink, 1990; Nakayama & Silverman, 1986; Treisman, 1988). In other words, not all feature searches are completed easily nor are all conjunction searches difficult.

Therefore, it would appear visual processing is more complicated than a simple feature versus conjunction distinction and to understand visual processing requires consideration of other factors which might be influencing visual processing. An alternative approach, the Attentional Engagement Theory originally proposed by Duncan and Humphreys' (1989), abandons this feature versus conjunction search distinction offering instead that search difficulty is a function of grouping based on similarity of the target to distractors and the similarity amongst distractors themselves.

The Attentional Engagement Theory (Duncan & Humphreys', 1989) proposes an initial parallel extraction of information across separable visual dimensions (color, shape, orientation, etc). Moreover, Duncan and Humphreys' (1992) argue not only for the extraction of this information but also for systematic grouping of incoming inputs based on their similarity to one another along given dimensions (proximity, spatial location, etc). These linked inputs are stored in a retinotopic organized termed the *weight-linkage* map. The concept of grouping is central to the Attentional Engagement Theory and allows for the consideration of how not only individual objects are processed in isolation but the importance of the relationships between objects. Therefore, one might ask what is grouping and how does it influence visual processing?

Grouping, at least in the scope of this paper, is understood as the segmentation of the visual field into figural units or categories based on similarity of inputs across certain visual dimensions (Han, Humphreys, & Chen, 1999). In general, the more similar the inputs are along a given dimension, the stronger they are grouped together. Grouping is not an entirely new concept and can be traced back to the philosophies of the gestalt psychologists. However, unlike other gestalt views, grouping has survived in contemporary studies of visual perception. Studies have shown grouping acts within a wide time course within visual processing, influencing perception both pre-attentively(Duncan, 1984; Duncan & Humphreys, 1989; Kahneman & Henik, 1981;

Kahneman & Treisman, 1984; Moore & Egeth, 1997; Neisser, 1967), and also in later stages of processing when binocular information is combined (Schulz & Sanocki, 2003).

Within visual search, grouping is thought to influence the perception and detectability of individual elements on a search display (Duncan & Humphreys, 1992). Initial reports of grouping in visual search demonstrate that discrimination of two target letters (T *vs.* F) is influenced by the spatial configuration of distractor elements (Banks & Prinzmetal, 1976; Prinzmetal & Banks, 1977). When the target is presented in a larger configuration defined by good continuation or closure, its discrimination is slower and less accurate than when the target is spatially apart from these configurations. In related work, Treisman (1982) showed that when elements are grouped by proximity, such that a unique feature of color or orientation defines the target within the cluster, search depends not on set size but on the total number of clusters; suggesting grouping occurs prior to the selection of the target element. Later studies explored the influence of other dimensions promoting grouping including connectivity (Trick & Enns, 1997; Rock, Nijhawan, Palmer, & Tudor 1992), spatial separation among elements "proximity" (Olds, Cowan, & Jolicoeur, 1999), contrast polarity (Enns & Kingstone, 1995), uniform connectedness (Han, Humpreys, & Chen, 1999), shared shape/contour (Beck, 1966; Quinlan & Wilton, 1998; Belongie, Malik, & Puzicha, 2002) and color (Kaptein, Theeuwes, & Van der Heijden, 1995). However, not all these dimensions are equal in the ability to influence perception and grouping. The importance of each of these grouping dimensions on visual perception varies between humans and other species of primates suggesting their importance might be related to species specific development within a certain visual environment (Spinozzi, Lillo, Truppa, & Castorina, 2009).

Humans are not always aware of grouping in visual processing. Grouping is shown to have an unconscious spreading influence on other elements which otherwise would not be grouped – a process termed induced grouping. Induced grouping was studied by Vickery (2008) using a repetition detection task. In this task, participants were asked to identify the repetition of shape within a series of simultaneously presented elements. As an example, participants might search for a repetition of a circle within an alternating series of triangles, squares, and circles. Vickery demonstrated that introducing a second task-irrelevant series of grouped elements (crosses), grouping on color and proximity were explored, affects detecting the repetition of a shape within the first series. Furthermore, Vickery should this unconscious influence of grouping can be negated by introducing a solid line segment segregating the two series illustrating the fragility of induced grouping.

Attentional Engagement Theory recognizes the importance of grouping on perception and explains visual search performance is mediated by grouping in two ways: between target and distractors and between groups of distractors (Duncan & Humphreys, 1989; Duncan & Humphreys, 1992). Specifically, search efficiency *decreases* with increasing target-distractor similarity. For example, strong similarity between target and distractors results in target and distractor grouping thereby making the target less discriminable (bottom of Fig. 1a) resulting in a difficult search. As the target and distractors become less similar there is less likelihood of grouping resulting in an easier search (compare top and bottom of Fig. 1a). This effect of target and distractor grouping has been well documented by others in the literature. Neisser (1963) first showed that a lettered target is much harder to detect when it is physically similar to distractors (i.e.

sharing the same shape and contours). Subsequent experiments have replicated this effect using letters (Corcoran & Jackson, 1977), color patches (Farmer & Taylor, 1980), lines varying in curvature (Treisman & Gormican, 1988), and contours varying in the size of a gap (Treisman & Souther, 1985).

a) b)

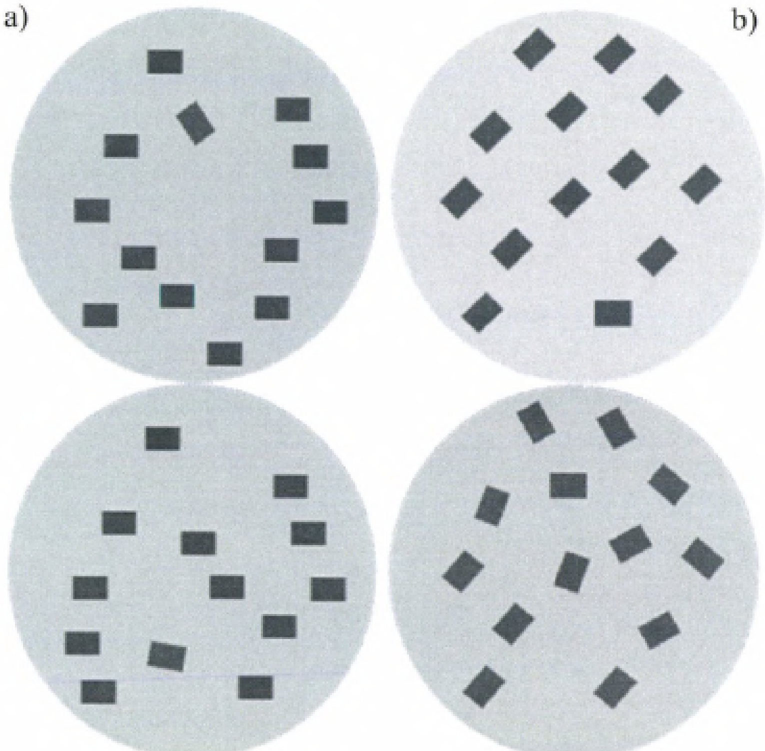


Figure 1. Two main influences of search difficulty according to Attentional Engagement Theory. a) shows how the target-distractor similarity relates to search difficulty. The display on top has a larger target-distractor difference than the bottom display and thus is much easier to search through. b) shows how distractor-distractor similarity also can influence search. The top display is a target among homogenously oriented distractors. The bottom display shows the same target among a set of heterogeneously oriented distractors making the search much more difficult.

Grouping of distractors can also be a determinate of visual search efficiency. Attentional Enagement Theory would argue that when distractors are more similar to one another, search is easier than when distractors are less similar (compare the top and bottom of Fig. 1b). In terms of distractors, grouping benefits search by permitting the suppression of a single group (Duncan and Humphreys, 1989). For example, when distractors are "homogenous" (top Fig. 1b) or more similar in nature they are grouped and rejected together. Conversely, when distractors are "heterogeneous" (bottom Fig. 1b) or less similar, grouping and rejection across linked distractors does not occur resulting in less efficient searches. In comparison to target-distractor grouping, there have been relatively fewer direct investigations of distractor grouping influence visual search since the majority of visual search studies use homogeneous distractors. However, that is not to say that distractor relationships are inconsequential to understanding search - studies investigating distractor grouping support the opposite. For example, distractors grouped along a simple feature such as color have been shown to aid practice effects whereas distractor not grouped such a feature hinder practice effects (Carrasco, Ponte, Rechea, Sampedro, 1998). Poisson and Wilkinson (1992) showed both varying the relative number of elements taken from two distractor types and how the spatial configuration of these distractors, thereby promoting grouping, can strongly influence search performance.

Although the visual search paradigm proves useful when approaching issues regarding visual processing it cannot offer explanations as to how processing occurs. Nevertheless, evidence from a range of visual search studies demonstrates the importance of modeling visual perception not simply as a process of encoding individual objects in isolation but building models which appreciate the interactions amongst elements. Specifically, grouping has been shown to have considerable influence on visual perception and search performance and therefore, under the visual search paradigm, investigations of grouping could yield potentially relevant information as to nature of visual perception. The Attentional Engagement Theory offers a simple yet testable model for interpreting how grouping influences search performance which will be explored in this paper as it relates to a new and plausible grouping dimension.

CONFIGURAL ASYMMETRIES: AN INTRODUCTION

a) b)

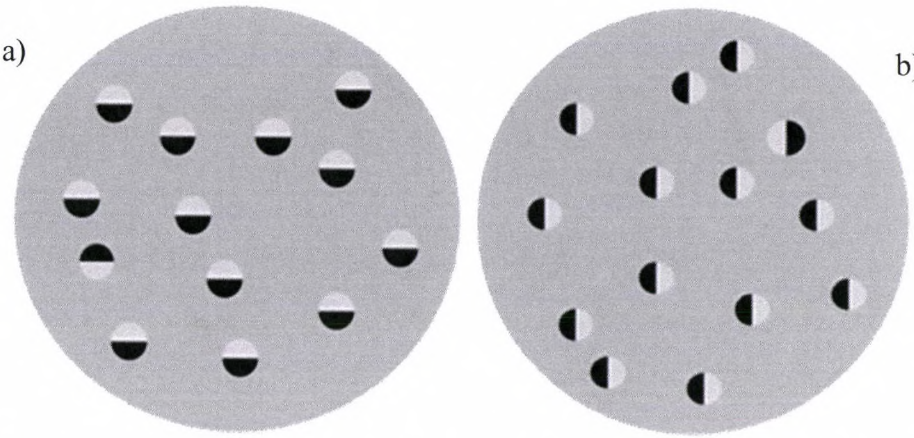


Figure 2. A demonstration of a configural asymmetry in which the horizontal display (left) is searched through faster and with fewer errors than the vertical display (right).

Previously it was discussed that grouping occurs along a number of given dimensions including: color, shape, connectedness, and proximity. Yet this list is not exhaustive of all the possible dimensions by which grouping might occur. The current study attempted to understand how the complex spatial relationship of mirror symmetry shared between search elements influences search by facilitating grouping. Recently, mirror symmetry has been identified as a possible dimension of grouping and has been studied under the visual search paradigm (Van Zoest, Giesbrecht, Enns, Kingstone, 2006; Roggeveen, Kingstone, & Enns, 2004). Mirror symmetry also was identified by the gestalt psychologists for its influence on grouping which corroborates this more recent claim. This study begins its investigation of mirror symmetry as it has been presented in the literature within the context of a new yet understudied visual search phenomena termed configural asymmetries.

Configural asymmetries refer to particular visual search phenomena in which the orientation of otherwise identical elements produces differences in search performance (Monnier, Atarha, Edler, & Birks, 2010). Figure 2 is an example of configural asymmetries. Search elements are bicolor disks oriented horizontally (Fig. 2a) or vertically (Fig. 2b). The target, the unique element in the display, is the mirror image of the distractors (e.g., bright-left /dark-right target with dark-left/bright-right distractors, Fig. 2b). Elements in both displays are identical except for a 90° rotation. This arguably subtle difference in orientation causes a large difference in search performance (Monnier et. al., 2010): finding the target takes longer when the elements are in a vertical orientation (Fig. 2b) compared to a horizontal orientation (Fig. 2a).

Figure 3. The figure is the cockpit display used in the space shuttle Columbia. The interface design used was highly complicated. These types of displays highlight the importance of understanding configural asymmetries and how the visual system inherently encodes information which shares mirror symmetry relationships.

These differences in search performance are surprising and important. Complex symbols, similar to those used in configural asymmetries, are routinely used to convey information. For example, the display NASA used for the 1980 Columbia Shuttle was complicated; conveying a range of critical information to the flight crew via numerous toggles and switches (Fig. 3). Considering the cost to train astronauts to use this complicated system and the consequences of making a mistake while in-flight, many questions were pondered on how to design the most intuitive and operator-friendly display. Knowing beforehand vertically oriented symbols are more time consuming and produce more errors than horizontally oriented symbols would be essential in this design process and optimizing operator usability.

Even though practical consequences for configural asymmetries clearly exist, a thorough theoretical account remains elusive. However, several accounts have been eliminated. Different patterns of eye movements in the two conditions (e.g., less efficient scanning in the vertical versus horizontal condition) have been ruled-out as the asymmetry persists with briefly presented displays in which eye movements are eliminated (Monnier et. al., 2010). Configural asymmetries can be produced using both familiar and unfamiliar stimuli (Roggeveen et. al., 2004). The shape of the elements is irrelevant as long as the target and distractors require left/right versus up/down judgments (Roggeveen et al., 2004; Van Zoest et. al., 2006). When controlling for incompatible response mapping (left/right motor responses for up/down objects) the effect still persists. The effect is not produced when the target is different from the distractors by a 90° rotation (Van Zoest et al., 2006). The effect is robust to extensive practice: observers completing over a thousand trials on the task still exhibit worse performance on vertical displays compared to horizontal displays (Monnier et al., 2010). Configural asymmetries are robust to color manipulations of the elements (unpublished measurements).

From the elimination of these possible explanations, two accounts of configural asymmetries have surfaced. Monnier et al. (2010) tentatively explain configural asymmetry as an object-based process arising from a fundamental difference in how the vertical and horizontal planes of an object are processed. Specifically, they argue that the up/down regions of an object are processed more efficiently than the left/right regions (Monnier et. al., 2010). This argument is grounded in the observation that vertical symmetry is abundant in nature; contributing to the arbitrary and confusable nature of the horizontal plane. Therefore, little benefit is found for exhibiting high sensitivity along the horizontal plane since the left/right regions are typically redundant in information and usually belong to the same vertically symmetric object (Bornstein, Gross & Wolf, 1978; Farrell, 1979; Gross & Bornstein, 1978). As a consequence, comparisons along the left/right regions of an object are inherently less informative and result in less sensitivity than up/down regions. This account is termed the Object Region Account since it defines configural asymmetries as differences in processing within various regions of an individual object.

Support for the Object Region Account can be traced to early studies of mirror confusability. Wolff (1971) was interested in the confusability of mirrored and non-mirrored stimuli positioned along the horizontal and vertical plane. Wolff's results showed discriminations across the left/right plane produced more errors than discriminations across the up/down plane – results which were reported in earlier studies of confusability along the horizontal plane in children (Sekuler and Houlihan, 1968).

Others have also demonstrated similar difficulties in making comparisons along the horizontal compared to vertical plane (Sutherland, 1960; Huttenlocher, 1967; Enns & Kingstone, 1997; Fecteau, Enns, & Kingstone, 2000). Neuro-physiological reports have also demonstrated this left/right versus up/down effect. Neurons in the inferotemporal region of the macaque brain show increased response when conducting up/down judgments compared to left/right judgments for mirror symmetric stimuli (Rollenhagen & Olson, 2000). Collectively, these studies are consistent with the Object Region Account and evince that left/right comparisons within an object are harder to conduct than up/down comparisons.

Roggeveen et al. (2004) propose a contextual account of configural asymmetries whereby mirror symmetry relationships between objects influence how they are grouped and processed. Specifically, objects sharing vertical mirror symmetry (e.g. p versus q) are perceptually more similar and therefore less distinguishable than objects sharing horizontal mirror symmetry (e.g. b versus p) (Cairns and Steward, 1970; Hershenson and Ryder, 1982; Bagnara, Boles, Simion, and Umilta, 1983). Qualitative measurements for this difference in perceptual similarity between the two symmetries was drawn from Hershenson and Ryder (1982) in which pairs of elements translated over the vertical axis were rated as more similar by observers than the same elements translated over the horizontal axis. Tying this to visual search, Roggeveen and colleagues argue that this increased similarity in vertical mirror symmetry increases the propensity to group the target together with the distractors thereby creating a much more difficult search (Roggeveen et. al., 2004). This increased likelihood to group the target with the distractors in the vertical compared to the horizontal condition is what drives configural asymmetries as shown in figure 2 (Roggeveen et al., 2004; Van Zoest et. al., 2006). Though few have directly compared vertical and horizontal mirror symmetry relationships among multiple elements, other studies also note difficulties when elements share vertical mirror symmetry (Davis, Shikano, Peterson, & Michel, 2003; Wolfe and Friedman-Hill, 1992). This account is termed the Inter-item Symmetry Account since the effect is attributed to mirror symmetry relations and how mirror symmetry influences grouping among elements on the search display.

UNRESOLVED QUESTIONS

There is a clear distinction in how these two accounts explain configural asymmetries. The Object Region Account (Monnier et al., 2010) attributes configural asymmetries to inherent differences in processing regions *within individual objects* - a consequence of the abundance of vertical symmetry in the natural environment. The Inter-item Symmetry Account (Roggeveen et al., 2004) attributes configural asymmetries to differences in perceptual similarity and grouping driven by mirror symmetry *between multiple objects*. Central to these differences is whether configural asymmetries are inherently object-based (Object Region account) due to the inspection of individual elements, contextual-based (Inter-item Symmetry account) driven by the grouping of multiple elements, or even perhaps an interaction of both accounts.

The following report attempted to isolate the Inter-item Symmetry Account of configural asymmetries to better understand these visual search phenomena and to investigate whether mirror symmetry is truly a dimension by which grouping occurs as reported by Roggeveen and colleagues (2004). By analyzing mirror symmetry separately from making left/right versus up/down judgments within individual object we can understand how both processes might contribute to search performance and understand whether mirror symmetry uniquely influences grouping of elements. To accomplish this, the authors first replicated a typical configural asymmetries experiment to obtain a baseline estimate of the effect. In the experiments following, stimuli which shared mirror symmetry relationships but did not require left/right or up/down judgments were created to isolate the mirror symmetry between search elements and to examine mirror symmetry's ability to promote grouping. Specifically, we were interested in whether differences in search performance between horizontal and vertical mirror symmetry could be obtained when target and distractors shared mirror symmetry relations (Experiment 2) and when distractors shared mirror symmetry relations (Experiment 3) - two ways dimensions of grouping, according to the Attentional Engagement Theory, influences performance in a visual search task.

EXPERIMENT 1: REPLICATING A CONFIGURAL ASYMMETRY

Stimuli typically used to study configural asymmetries are bipartite objects bisected either horizontally or vertically (Fig. 2, Monnier et. al., 2010). This experiment set out to replicate a configural asymmetry using bipartite stimuli, bisected horizontally or vertically, containing previously untested blue/yellow chromatic information. Stimuli of this nature do not differentiate well between the two accounts of configural asymmetries: one could argue that differences in search performance between conditions are driven by left/right versus up/down judgments across regions of individual elements (Object-Region Account) or by mirror symmetry relationships between target and distractors (Inter-item Symmetry Account). Nevertheless, results of this experiment served as a good comparison to results in the following experiment which used stimuli that preserved mirror symmetry relationships but did not require left/right or up/down judgments within elements. In this study, we predicted a typical configural asymmetries effect to occur: vertical displays would be searched more slowly and produce more errors than horizontal displays.

METHODS

Participants

Ten participants were selected from the Colorado State University's undergraduate research pool. Participants were screened for normal or corrected-to-normal acuity (20/20) and normal color vision. Participants provided their consent and were treated in an ethical manner as detailed by the IRB at the institution.

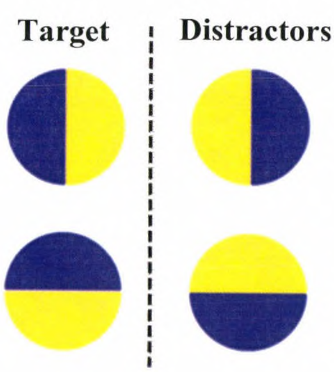
Stimuli/Apparatus

Search displays were viewed on a 19" LCD monitor (Viewsonic, model VA1926W, resolution 1440 by 900 pixels, 75Hz) at a distance of one meter. Stimuli measured approximately 1 deg of visual angle in size. The elements themselves were bipartite disks, split vertically or horizontally, with blue/yellow chromatic information (l = .667, s = 3.41; l = .666, s = .201) at a luminance of 40 cd/m^2. Chromatic values are presented in LMS color space in which values reflect response activity of the three individual cone photoreceptors (Long "L", Medium "M", & Short "S") at a given luminance level. Elements were presented pseudo-randomly on the display given two constraints: first, the elements were presented within an annulus measuring 12 and 2 deg outer and inner diameter, respectively. Second, elements were separated by a minimum distance of 0.12 deg from each other (measured center–to-center). Elements were presented on a gray background (l = .666, s = 1.007) at a luminance of 20 cd/m^2. Set size, total number of elements presented simultaneously on the display, was held constant at 24 elements. Graphics were rendered by an ATI Radeon 4800 GT video card powered by an Apple G4. Observer responses were collected using a Gravis gamepad.

Procedure

A latency visual search paradigm was used requiring participants to search through a display containing multiple elements to determine the presence or absence of a unique target element. Participant responses were collected on a gamepad. An initial button press stopped the timer and removed the search display from the screen followed by a secondary button press recording target present/absent responses. Reaction time was measured from the time of the display onset until the first button press. Incorrect responses were indicated by a double auditory beep. Throughout the entirety of the experiment a central fixation point was present and participants were instructed to maintain fixation prior to the start of each trail. Before the start of the experiment, participants completed a total of eight target-present practice trials - half the practice being vertical displays (Fig. 4, Condition 1) and the other half horizontal displays (Fig. 4, Condition 2) randomly intermixed. The purpose of the practice trials was to familiarize participants with demands of the task and the process of recording responses on the gamepad. Practice trials were discarded and not considered for analysis.

Figure 4



	Target / Distractors	Description
Condition 1		Vertical objects. Elements could be explained as requiring left/right judgments (Monnier et. al., 2010) or by as vertical mirror symmetry between target and distractors (Roggeveen et. al., 2004; Van Zoest et al., 2006).
Condition 2		Horizontal objects. Elements could be explained as requiring up/down judgments (Monnier et. al., 2010) or by as horizontal mirror symmetry between target and distractors (Roggeveen et. al., 2004; Van Zoest et al., 2006).

Two types of displays were tested: vertical or horizontal (Fig. 4). For the two conditions there were 30 target-present and 30 target-absent trials resulting in a total of

120 trials. All trials were presented in single block with display orientation and target present/absent randomly intermixed. Mean reaction times and total errors for each of the two orientations condition were computed for both target present and absent trials separately using only correct responses.

RESULTS

This experiment replicated typical configural asymmetries – horizontal displays resulted in better performance than vertical displays. For target present trials (Fig. 5), horizontal displays (M = 3634.70, SD = 622.49) were searched through more quickly than vertical displays (M = 4989.20, SD = 784.95); $F(1,9) = 122.807$, $p < 0.05$; $\eta_p^2 = .932$. Also, there were fewer errors committed on horizontal displays (M = 3.40, SD = 2.67) than vertical displays (M =9.40, SD = 4.45); $F(1,9) = 26.129$, $p < 0.05$; $\eta_p^2 = .744$.

Similar effects were obtained in target absent trials (Fig. 6). Again horizontal displays (M = 6999.60, SD = 1700.84) resulted in faster search than vertical displays (M = 8336.00, SD = 1720.91); $F(1,9) = 65.89$, $p < 0.05$; $\eta_p^2 = .880$. No differences in error rates were found.

DISSCUSSION

In this experiment, a typical configural asymmetries experiment was replicated in which vertical displays were searched through faster than horizontal displays. The size of this effect was non-negligible with the magnitude, the proportion of vertical performance over horizontal performance, for target present data reaching 1.37x, meaning vertical displays required 1.37x longer to process than horizontal displays. However, it remained unclear from this experiment whether these found differences were due to left/right versus up/down decisions within objects, differences in grouping due to mirror symmetry, or a combination of both. The subsequent experiments set out to distinguish between the two proposed accounts of configural asymmetries and attempted to separate and analyze how mirror symmetry influences performance.

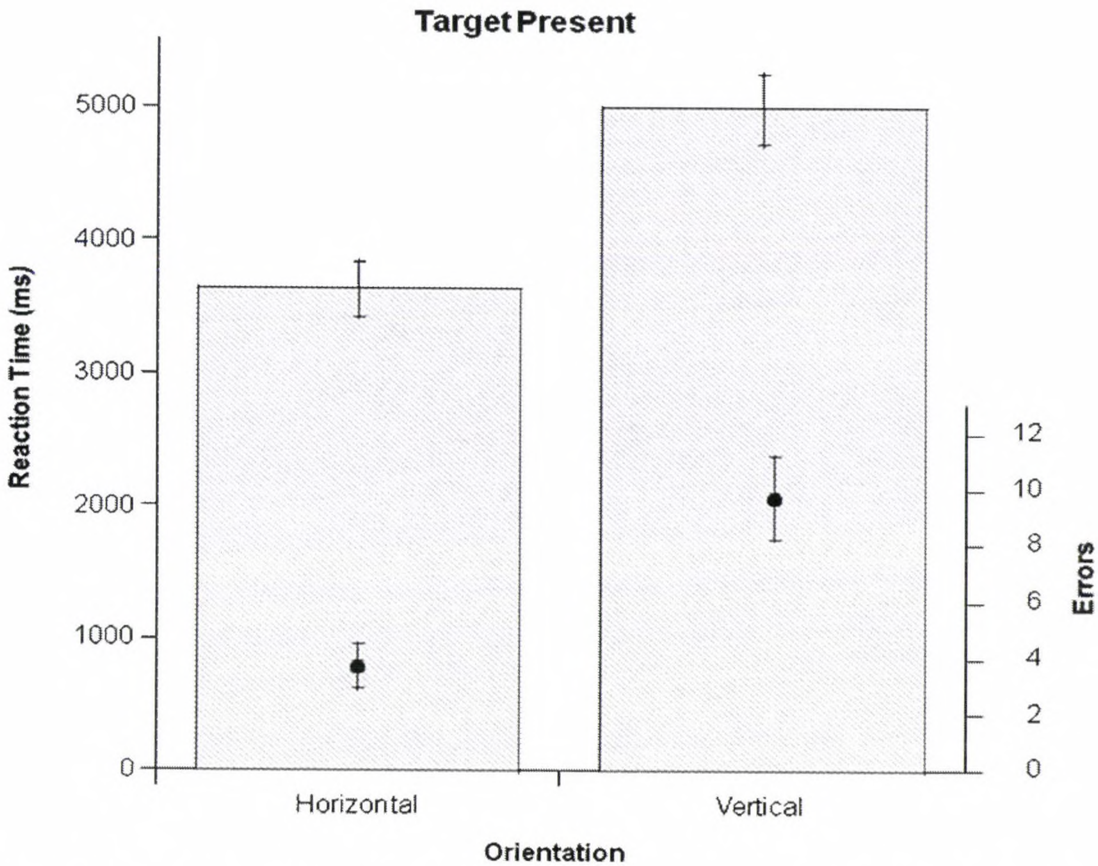


Figure 5. Reaction time and errors plotted as a function of orientation for target present trials. Error bars represent one standard error of the mean. Horizontal displays resulted in faster reaction times and fewer errors than vertical displays.

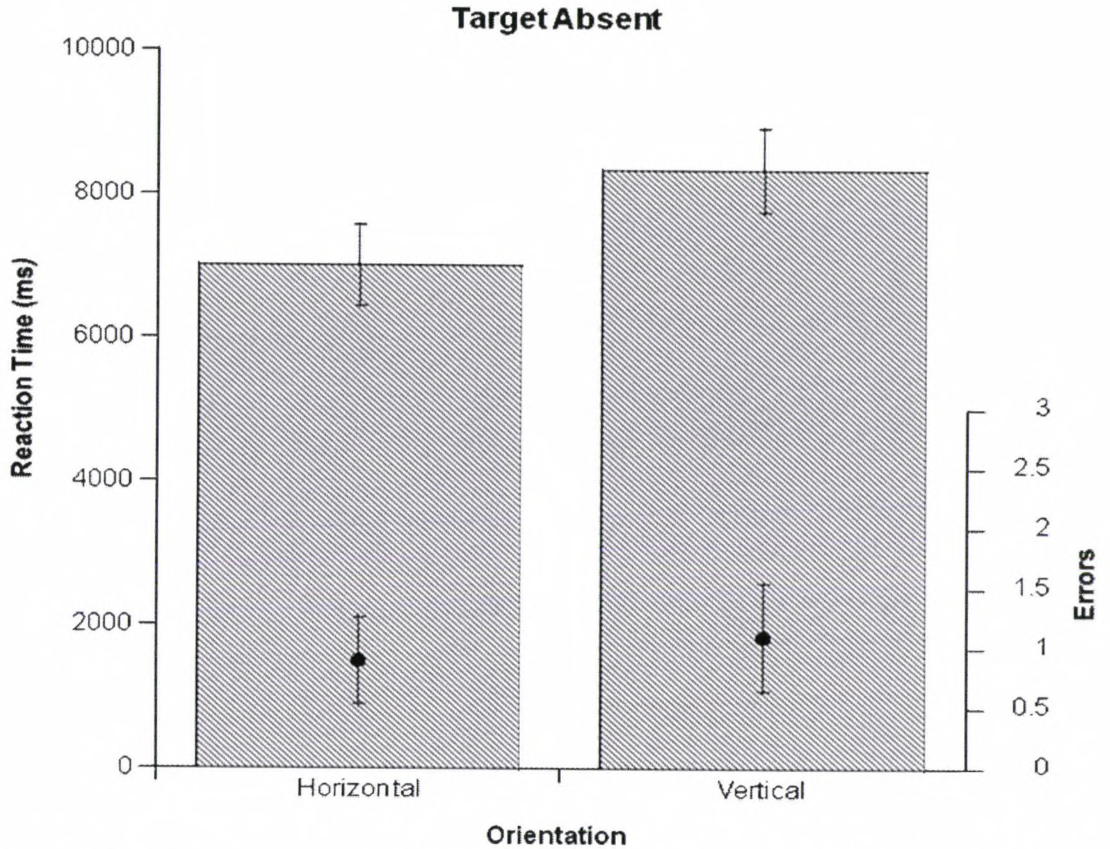


Figure 6. Reaction time and errors plotted for the two element orientation conditions for target absent trials. Error bars represent one standard error of the mean. Horizontal displays resulted in faster reaction times than vertical displays.

EXPERIMENT 2: ISOLATING MIRROR SYMMETRY

In this experiment, a new set of stimuli were used to test the unique contribution of mirror symmetry between target and distractors. This experiment was identical in methodology to the previous experiment except stimuli were now bisected obliquely (Fig. 7). Oblique bisection produced stimuli in which left/right versus up/down judgments within individual objects were no longer required yet vertical and horizontal mirror symmetry relationships between target and distractors persisted. Unlike the stimuli in the previous experiment, these new stimuli were ideal in distinguishing between the Object-Region Account and Inter-item Symmetry Account: given that the stimuli no longer required left/right or up/down discriminations the Object-Region Account would predict no differences between search conditions, whereas, given mirror symmetry relations between target and distractors persisted, the Inter-item Symmetry Account would predict that horizontal mirror symmetry would produce faster reaction times than vertical mirror symmetry conditions due to differences in the grouping of elements between the two conditions.

Apart from the effects of grouping due to mirror symmetry, this experiment indirectly investigated the effect of distractor heterogeneity on search difficulty – a factor crucial to performance as noted by Duncan and Humphreys (1989) and Poisson and Wilkinson (1992). To test distractor heterogeneity, two sets of distractor groups were used and the relative number of distractors taken from each group was varied systematically between seven ratios. Set size was held constant across these ratios creating conditions that varied in terms of overall dominance of one distractor type over the other – from conditions in which the target shared vertical mirror symmetry with all distractors, to conditions in which half the distractors shared vertical mirror symmetry with the target and the other distractors sharing horizontal mirror symmetry, to conditions in which the target shared horizontal mirror symmetry with all distractors. If distractor heterogeneity influences search as proposed by Duncan and Humphreys (1989), we expected the two homogenous distractor conditions, in which distractors were all identical to one another, to produce faster reaction times than heterogeneous distractor conditions.

METHODS

Participants

Nineteen participants were selected from the Colorado State University's undergraduate research pool. Participants were screened for normal or corrected-to-normal acuity (20/20) and normal color vision. Participants provided their consent and were treated in an ethical manner as detailed by the IRB at the institution.

Stimuli/Apparatus

Stimuli used in this experiment were identical in chromatic information and size to the stimuli in the previous experiment. A target was presented with two types of distractors: D1 distractors shared horizontal mirror symmetry with the target and D2 distractors shared vertical mirror symmetry with the target (Fig. 7). The presentation of stimuli on the display and the apparatus used to produce the displays were identical to the previous experiment.

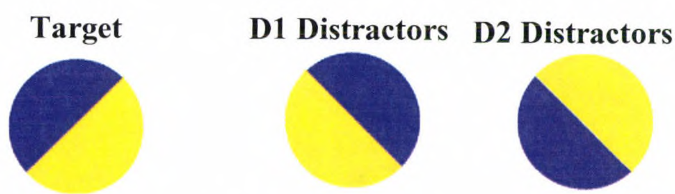


Figure 7. Stimuli used in Exp. 2 which isolated mirror symmetry. The target shared vertical mirror symmetry with D1 and horizontal mirror symmetry with D2.

Procedure

The procedure for this experiment was identical to the previous experiment except two distractors types (D1 and D2) were presented simultaneously and the relative number of distractors taken from the two groups was varied, holding set size constant at 24. The target, when present, would be randomly substituted for either a D1 or D2 distractor to keep set size fixed at 24 for target present trials.

Seven distractor ratios (relative number of D1 to D2 distractors) were tested: 1:0, 5:1, 2:1, 1:1, 1:2, 1:5, 0:1. A 1:1 ratio represented a condition containing an equal number of D1 and D2 distractors whereas ratios of 1:0 and 0:1 represented conditions where distractors were homogenous sharing vertical and horizontal mirror symmetry with the target, respectively. This ratio can also be expressed as the percent dominance of horizontal distractors (D2) over vertical distractors (Fig. 8, far right column) with values ranging from 0% (all distractors vertically symmetric with target) to 100% (all distractors horizontally symmetric to the target). For convenience, results for the manipulation of distractor heterogeneity will be expressed in terms of percent dominance of horizontal distractors.

Ratio	# of D1 Elements	# of D2 Elements	Ratio (D1:D2)	% Horizontal Distractors
1	24	0	1:0	0.00%
2	20	4	5:1	16.67%
3	16	8	2:1	33.33%
4	12	12	1:1	50.00%
5	8	16	1:2	66.67%
6	4	20	1:5	83.33%
7	0	24	0:1	100.00%

Figure 8. Homogeneous and heterogeneous conditions with the relative number of D1 and D2 distractors. Ratio 1 and 7 represented homogenous distractors which shared vertical and horizontal mirror symmetry with the target, respectively. Intermediate ratios (2-6) represented heterogeneous distractor conditions.

Participants completed a single block of trails which randomly interleaved distractor ratio. For each ratio, 15 target present and 15 target absent trials were presented resulting in 280 total trials. Seven target-present practice trials (one for each ratio condition) were presented at the beginning of a block of trials. These practice trials were not included in the data analysis.

RESULTS

Figure 9 displays reaction time for target present trials as a function of percent dominance of horizontal distractors. The obliquely bisected stimuli, which preserved mirror symmetry but did not require left/right or up/down judgments within elements, produced differences in search performance. Comparisons of the two homogenous conditions showed that displays containing horizontal mirror symmetry between target and distractors resulted in faster processing (M = 3965.33, SD = 1351.37) than displays containing vertical mirror symmetry (M = 4257.64, SD = 1484.15); $t(18) = 2.099$, $p < 0.05$; $\eta_p^2 = .205$. However, for target absent trials (Fig. 10), no differences between vertical (M = 5981.33, SD = 1638.59) and horizontal (M = 6266.17, SD = 1669.17) mirror symmetry were found.

These findings of the target absent were not inconsistent with the Inter-item Symmetry Account given that target absent displays contained no mirror symmetry relationships between search elements. This difference in target present data supported the Inter-item Symmetry Account demonstrating the effect of mirror symmetry grouping; the target was more similar to distractors in vertical mirror symmetry than horizontal symmetry and therefore more likely to be grouped with distractors resulting in differences in search performance. Also, these results supported mirror symmetry uniquely influences search performance apart from left/right versus up/down judgments.

In addition to showing an effect of mirror symmetry, the data showed indirect support of the effect of distractor heterogeneity upon search. In both present/absent trials the homogenous conditions resulted in better performance than the heterogeneous distractor conditions. These results are supportive of Duncan and Humphreys (1989) and Poisson and Wilkinson (1992) claims that relationships between distractors and their shared similarity can influence search performance.

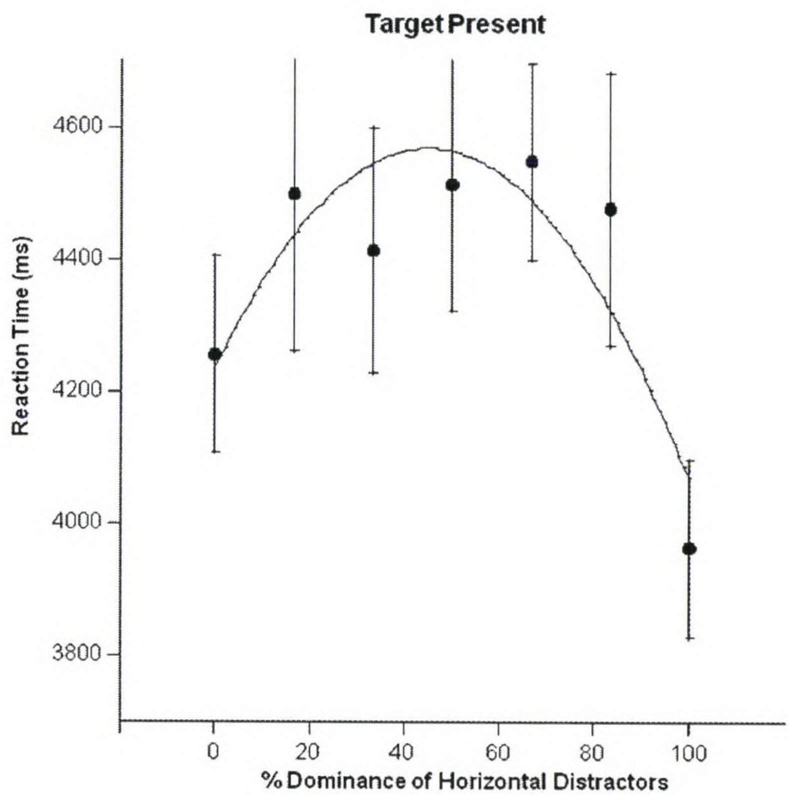


Figure 9. Reaction time as a function of dominance for target present measurements. Error bars are one standard error of the mean. Heterogeneous displays were more difficult to search through than homogenous distractors. Comparisons between the two homogenous distractor conditions show that displays containing horizontal mirror symmetry were searched through faster than vertical mirror symmetry displays.

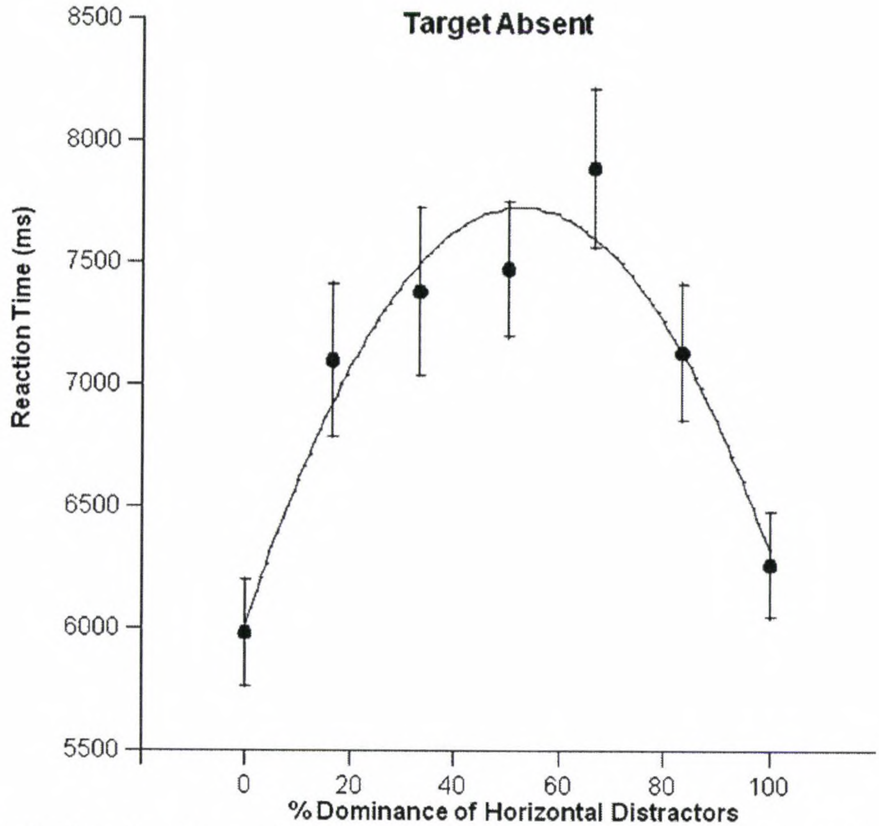


Figure 10. Reaction time as a function of dominance for target absent measurements. Error bars are one standard error of the mean. Heterogeneous displays were more difficult to search through than homogenous distractors. Comparisons between the two homogenous distractor conditions show no difference between horizontal and vertical mirror symmetry.

DISCUSSION

The results of this experiment provided convincing evidence that mirror symmetry alone can influence search performance lending weight to the Inter-item Symmetry Account. Measurements showed that when target and distractors shared mirror symmetry relationship but no longer required left/right versus up/down judgments, vertical mirror symmetry resulted in poorer performance than horizontal mirror symmetry as noted in the previous experiment. Since target and distractors shared this mirror symmetry relationship, the vertical mirror symmetry condition resulted in *greater* target-distractor similarity than in the horizontal mirror symmetry condition. Again the reasoning for these differences in search performance is attributed to how objects sharing vertical mirror symmetry are more similar to another and therefore more likely to be grouped than objects sharing horizontal mirror symmetry. Secondly, these results demonstrated the importance of distractor relationships to search performance. In general, conditions in which distractors themselves were more similar "homogenous" resulted in better performance than conditions in which distractors were less similar "heterogeneous".

Though the results of this experiment provided evidence for mirror symmetry being a dimension of grouping, the evidence for these claims have only been partially explored. There is additional benefit in investigating how mirror symmetry influences search performance when shared between distractors; since distractor relationships, too, are important in understanding visual processing. As proposed by Duncan and Humphreys (1989), increased similarity between distractors results in more efficient search. The current report argue for a difference in similarity between objects sharing horizontal and vertical mirror symmetry; with vertical mirror symmetry creating a stronger similarity effect than horizontal mirror symmetry. Therefore, if this is the true nature of mirror symmetry's influence on grouping then it is expected that when mirror symmetry is held between distractors a benefit for vertical mirror symmetry ought to be found. These conclusions are based on the idea that vertical mirror symmetry in distractors should *increase* similarity between distractors whereas horizontal mirror symmetry *decrease* similarity between distractors. If consistency in the effects of mirror symmetry on search between target and distractors and groups of distractors can be found then it would create a stronger claim for mirror symmetry being a dimension of grouping.

EXPERIMENT 3: MIRROR SYMMETRY AMONGST DISTRACTORS

The following experiment investigated how mirror symmetry, when held between distractors, influences search performance. Mirror symmetry relationships between distractors were previously studied by Roggeveen and colleagues (2004). Using distractors sharing horizontal/vertical mirror symmetry, Roggeveen (2004) produced differences in search performance whereby horizontal symmetry resulted in better performance than vertical symmetry. However a limitation of these results was that the target shared mirror symmetry relationships with one of the distractor groups (e.g. a target  among  and  distractors). In a broader sense, Roggeveen's results contradict the premise that vertical mirror symmetry increases similarity between objects whereas horizontal mirror symmetry decreases similarity. It would be expected that if vertical mirror symmetry creates objects that are more similar, then when held between distractors, vertical mirror symmetry should produce better search performance than horizontal mirror symmetry. Currently it remains unclear from their report whether symmetry between target and distractors or mirror symmetry between distractors drove the benefit for horizontal displays.

This study re-explored mirror symmetry among distractors while controlling for target and distractor mirror symmetry relationships. Instead of using a conjunction of shape and removal of a feature to define the target element, as in Roggeveen et al. (2004), the target in this experiment differed from the distractors by a rotational difference. The advantage of using rotational relationships between the target and distractors is that rotations have been shown to not produce differences in search performance (Van Zoest et al., 2006) and can be quantifiably measured and controlled. Under the assumption that increasing distractor similarity increases search performance, we predicted that vertical symmetry between distractors would result in easier searches than horizontal mirror symmetry. Our rationale was that if distractors sharing vertical mirror symmetry are perceived as more similar to one another and hence grouped together then these distractors should be rejected as a whole more easily resulting in superior search performance in comparison to distractors sharing horizontal mirror symmetry which are not as similar or grouped together and therefore not as likely to be rejected as a whole.

METHODS

Participants

Twenty-nine participants were selected from the Colorado State University's undergraduate research pool. Participants were screened for normal or corrected-to-normal acuity (20/20) and normal color vision. Participants provided their consent and were treated in an ethical manner as detailed by the IRB at the institution.

Stimuli/Apparatus

Chromatic information and the size of the stimuli were identical to previous experiment. The equipment used to render graphics and collect responses also remained the same. The arrangement of search elements on the display remained the same as the previous experiments. Set sizes of 8, 16, and 24 were tested.

Procedure

The procedure for this experiment was similar to the previous experiment, and again a target was presented against two sets of distractors. These two distractor sets were equal in number of elements. The target randomly took the place of one of the distractors (either a D1 or D2 substitution) to keep set size constant throughout a block of trials.

In this experiment distractors either shared horizontal or vertical mirror symmetry and the target was oriented either horizontally or vertically. In all the conditions, the difference between the distractors and target remained constant at 45° rotational difference. To test for possible interactions between features of the target and distractor symmetry relationships, the target's colors were reversed in the experiment; a manipulation referred to as "phase". For instance, a target element might be a bipartite disk split vertically – in the regular phase the colors of the disk might be blue-left/yellow-right while in the reversed phase the color would be yellow-left/blue-right. The manipulation of phase also prevented observers from restricting search to one distractor type whose color locations corresponded to those of the target (e.g. inspecting only distractors with blue-left/yellow-right configuration if the target colors were as arranged such) and reduced their expectancy of the target. By convention, all elements shown in Fig. 11 were termed *regular* phases whereas elements shown in Fig. 12 were named *reversed* phases.

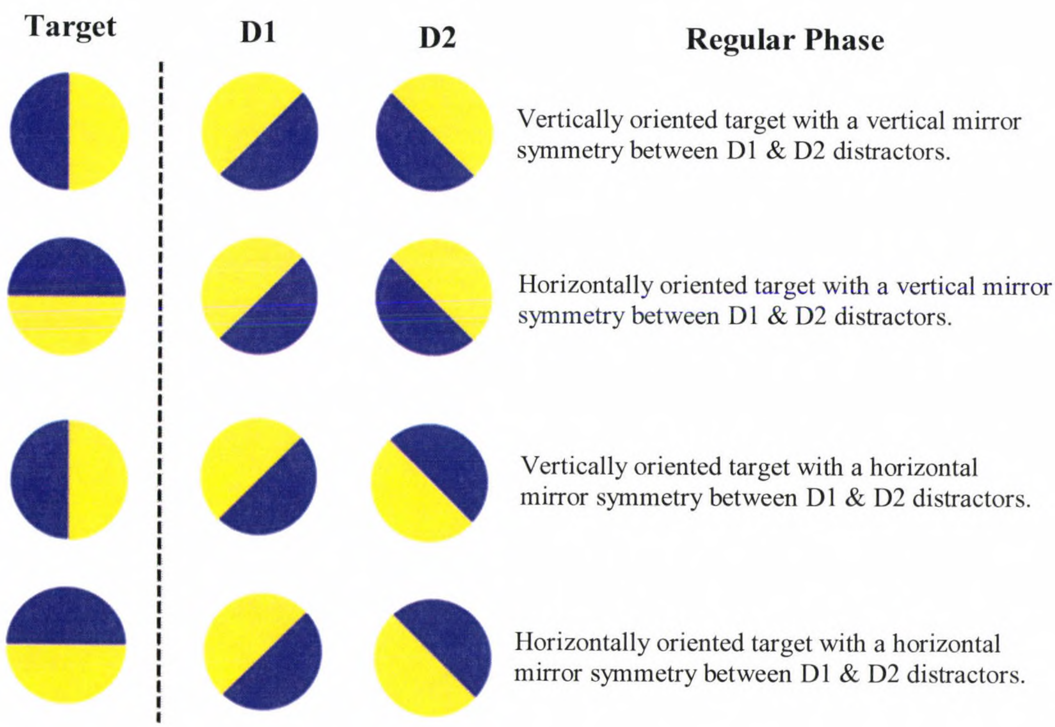


Figure 11. Manipulations of distractor symmetry (horizontal or vertical) and target orientation (horizontal or vertical) for the "regular" phase.

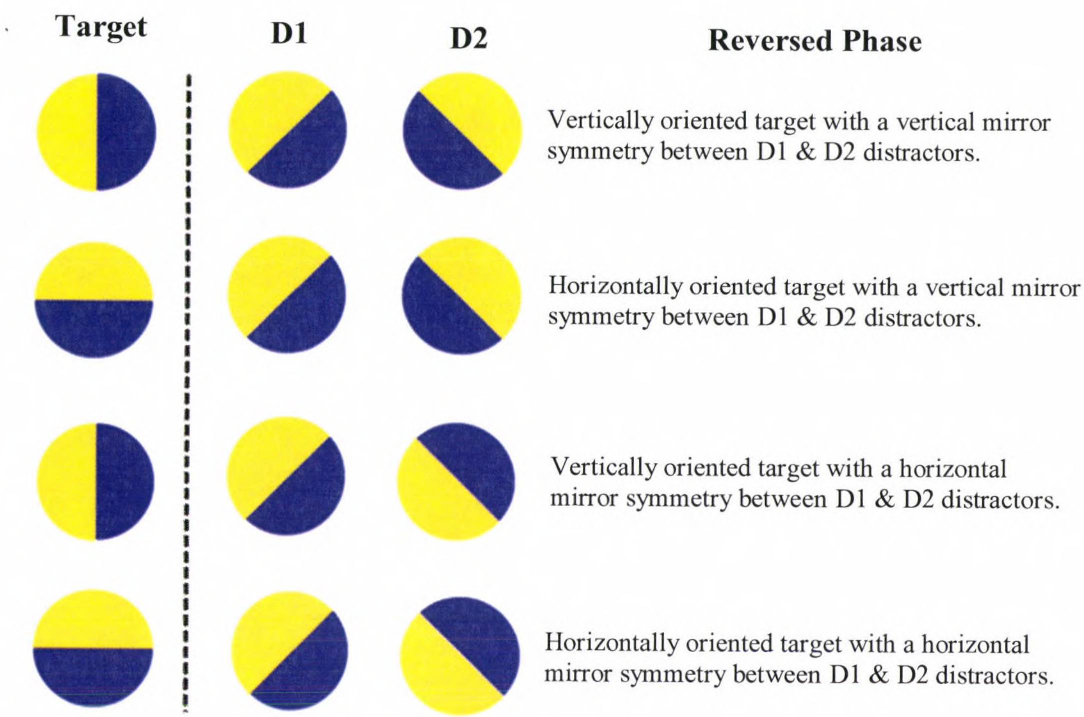


Figure 12. Manipulations of distractor symmetry (horizontal or vertical) and target orientation (horizontal or vertical) for the "reversed" phase.

Participants completed three blocks of trials for the three set sizes tested (8, 16, 24). Within each block distractor symmetry, phase, and target orientation were randomly interleaved within each block. For each of the eight conditions (2 distractor symmetries x 2 target orientations x 2 phases), 10 target-present trials and 5 target absent trials per each of these eight conditions were randomly presented resulting in 120 trials per block. Eight practices (one trial per each of the eight possible conditions) were included before the start of each block. As in the previous experiments, practice trials were discarded and not included in the data analysis. For each block, mean reaction times and total errors for each of the eight conditions were computed separately for both target present and absent trials using only correct responses.

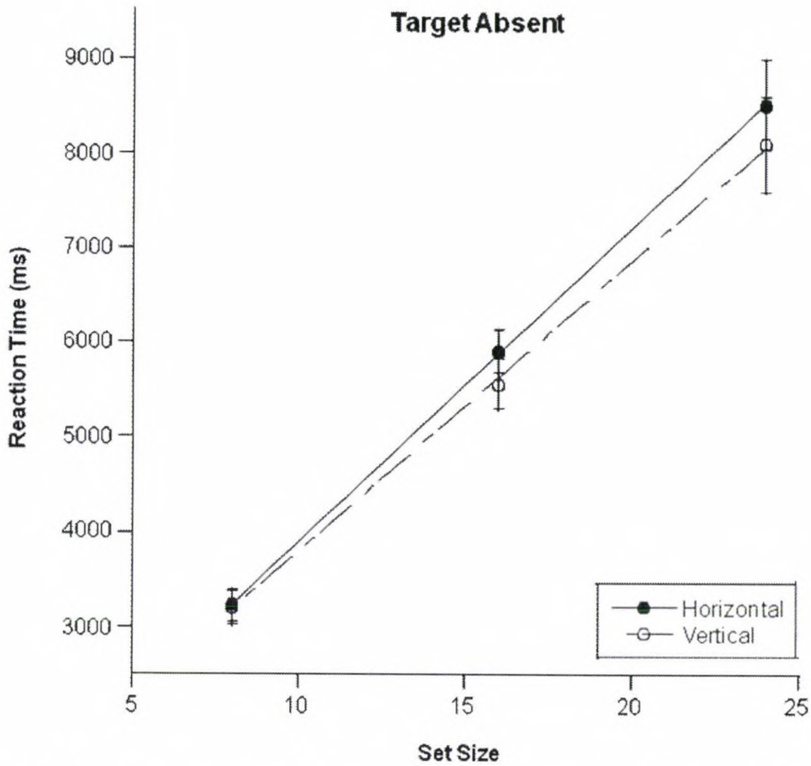


Figure 13. Reaction time as a function of set size for target absent data. Error bars represent one standard error of the mean. Solid symbols represent horizontal distractor symmetry. Solid symbols represent horizontal distractor symmetry. Open symbols represent vertical mirror symmetry.

Since target orientation and phase were manipulations of the target element, they were not relevant in the target absent data and observations from these manipulations were averaged together for each participant. This resulted in six conditions of interest for target absent data: set size (8, 16, 24) and distractor symmetry (horizontal and vertical). For the target absent analysis (Fig. 13), set size significantly affected search performance ($F(2, 54) = 94.27$, $p < 0.05$, $\eta_p^2 = .777$); the more elements presented the more difficult the search. More importantly vertical distractor symmetry ($M = 5702.86$, $SD = 2949.10$) resulted in better search performance than horizontal distractor symmetry ($M = 5948.50$, $SD = 2955.05$); $F(1,54) = 7.131$, $p < 0.05$, $\eta_p^2 = .209$.

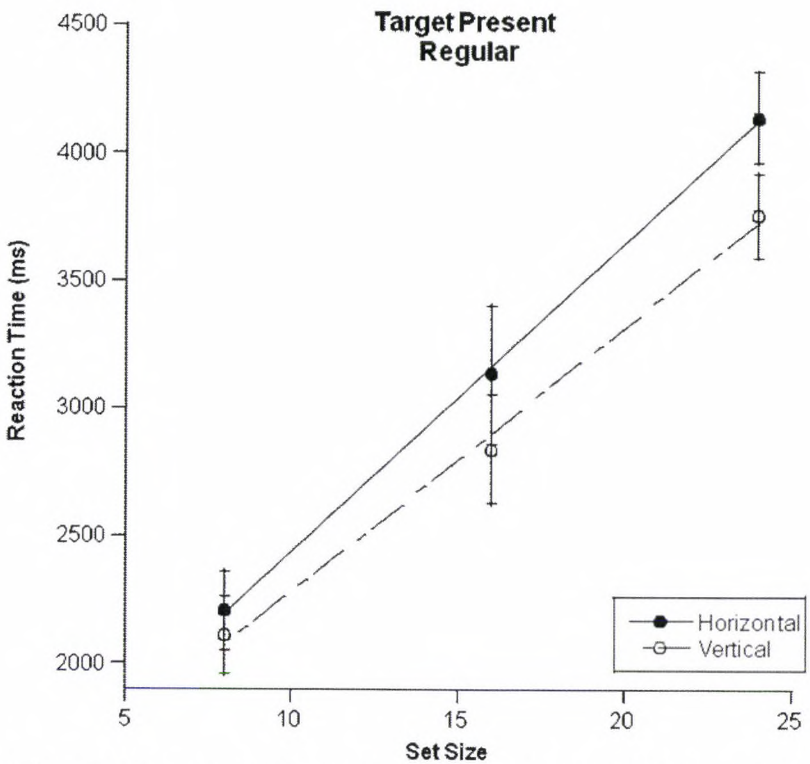


Figure 14. Reaction time as a function of set size for target present data for only the "regular" phase.. Error bars represent one standard error of the mean. Solid symbols represent horizontal distractor symmetry. Open symbols represent vertical mirror symmetry.

Analysis of target present data exhibited similar trends to those found in target absent data. Unlike target absent analysis, both the manipulations of phase and target orientation were considered for target present trials. For target present trials, increasing set size made search more difficult, $F(2,54) = 28.80$, $p < 0.05$, $\eta_p^2 = .516$, the more elements presented simultaneously the harder the search. As for the contribution of mirror symmetry, an interaction between phase and distractor mirror symmetry was observed; $F(1,54) = 13.136$, $p < .05$, $\eta_p^2 = .327$. Differences between the mirror symmetries were only obtained with target's of regular phases (Fig. 14), with vertical distractor mirror symmetry (*M* = 2814.24, *SD* = 2975.67) producing faster reaction times than horizontal distractor mirror symmetry (*M* = 3037.66, *SD* = 2610.42); F(1, 27) =

10.08, $p < 0.05$, $\eta_p^2 = .373$). These differences between the two types of distractor mirror symmetry were not demonstrated in the reversed phases (Fig. 15).

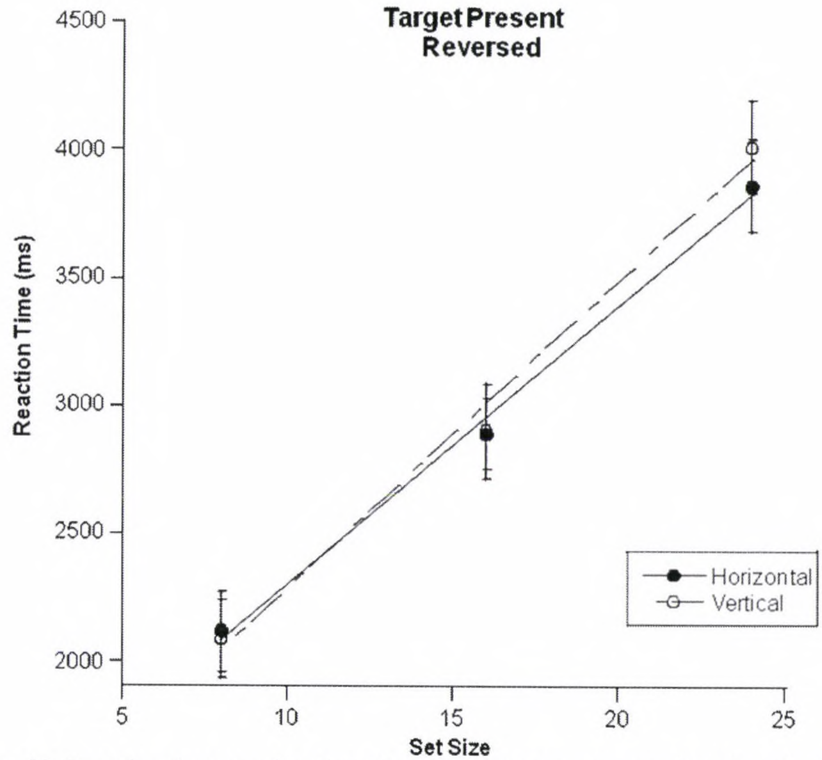


Figure 15. Reaction time as a function of set size for target present data for only the "reversed" phase. Error bars represent one standard error of the mean. Solid symbols represent horizontal distractor symmetry. Open symbols represent vertical mirror symmetry.

DISCUSSION

Results from the present experiment and those from the previous support the notion mirror symmetry influences grouping: both when symmetry relationships are held between target and distractors and between groups of distractors. Moreover, a simple description of how mirror symmetry influences grouping emerges: objects that share vertical mirror symmetry are perceived as more similar and therefore more likely to be grouped than objects sharing horizontal mirror symmetry. According to Attentional

Engagement Theory, search performance is worse when a target is more similar to distractors. Therefore when mirror symmetry between target and distractors was tested, a benefit for horizontal mirror symmetry was found since the target was less similar to distractors in this condition. More importantly, the opposite but expected effects were found when mirror symmetry was held between distractors; vertical mirror symmetry resulted in better search performance. Again this was predicted by Attentional Engagement Theory; when distractors are more similar (vertical mirror symmetry) search performance should be more efficient. Claims similar to these were made and justified by the experiments of Wolfe and Friedman-Hill (1992). Their results support that vertical mirror symmetry produces better search performance than oblique symmetries because of increased grouping and reduced heterogeneity among distractors.

Though this simple claim is appealing, it is prudent to note that one caveat. Only for conditions in which the target was of regular phase were differences between horizontal and vertical mirror symmetry produced. This is an interesting, albeit, unexpected effect that highlights that visual processing is understood as a combination of both target-distractor relationships and distractor relationships and not an effect of either of these relationships in isolation.

GENERAL DISCUSSION

One purpose of this report was to test whether mirror symmetry alone produced differences in grouping which would translate to differences in search performance; both when target and distractors shared mirror symmetry (Exp. 2) and when distractors shared mirror symmetry (Exp. 3). The results clearly supported this assumption and offered evidence supporting that mirror symmetry is a dimension in which objects are grouped, similar in fashion as to how other known grouping dimensions operate such as spatial separation (Olds *et al.,* 1999), contrast polarity (Enns and Kingstone, 1995) and color (Kaptein *et al.,* 1995). This is supported by the observed reversal in performance of mirror symmetry when testing mirror symmetry between target and distractors and groups of distractors. Performance on objects sharing mirror symmetry depended on whether these relationships were held between target and distractors or between distractors themselves.

When target and distractors share mirror symmetry, horizontal symmetry produced better search performance than vertical symmetry (Exp. 1 & 2). Roggeveen and colleagues (2004) argue that this horizontal mirror symmetry benefit was due to how objects sharing mirror symmetry are processed and grouped by the visual system (Cairns and Steward, 1970; Hershenson and Ryder, 1982; Bagnara et al., 1983; Roggeveen et. al., 2004; Van Zoest et. al., 2006) which appears plausible given the present results. According to their Inter-item Symmetry account, when the target shares horizontal mirror symmetry with distractors the target is perceived as less similar to distractors and therefore less likely to be grouped among distractors. These claims were investigated following the understanding of grouping according to the Attentional Engagement Theory. The Attentional Engagement Theory argues that a target is more salient and hence easier to find when it is less likely to be grouped with distractor elements. Findings of experiment two, where mirror symmetry was isolated, were consistent with the predictions of Attentional Engagement Theory and the Inter-item Symmetry Account rationale of grouping due to mirror symmetry shared between target and distractors.

Secondly, when distractors shared mirror symmetry, vertical symmetry produced better search performance (Exp. 3). This reversal in performance between the results of the second and third experiment can be explained by differences in the effects of grouping among target and distractors and groups of distractors. According to Attentional Engagement Theory, when distractors are more likely to be grouped (vertical mirror symmetry) this allows for that set of grouped distractors to be rejected as a whole which aides search performance for identifying the target. When distractors are not as likely to be grouped (horizontal mirror symmetry) they cannot be rejected as a whole thereby making search for the target element more difficult.

This performance reversal for vertical compared to horizontal mirror symmetry for distractors is inconsistent with previous reports of mirror symmetry in visual search. Previous reports have demonstrated that horizontal mirror symmetry produces better search performance than vertical mirror symmetry even when symmetry is shared among distractors (Roggeveen et. al., 2004). An example of the stimuli used in the Roggeveen study is presented in figure 16. One caveat to their stimuli is that the target shared mirror symmetry with one of the distractor groups for both conditions (compare the target in both conditions to the second distractor type).

These reports simplify the story of mirror symmetry and grouping: objects sharing vertical mirror symmetry are perceptually more similar to one another and therefore more likely to be grouped together than objects sharing horizontal mirror symmetry. When mirror symmetry is shared between target and distractors, less grouping will aid in visual search therefore horizontal mirror symmetry will result in better search. When mirror symmetry is shared between distractors, more grouping between distractors will aid in visual search therefore vertical mirror symmetry will result in better search.

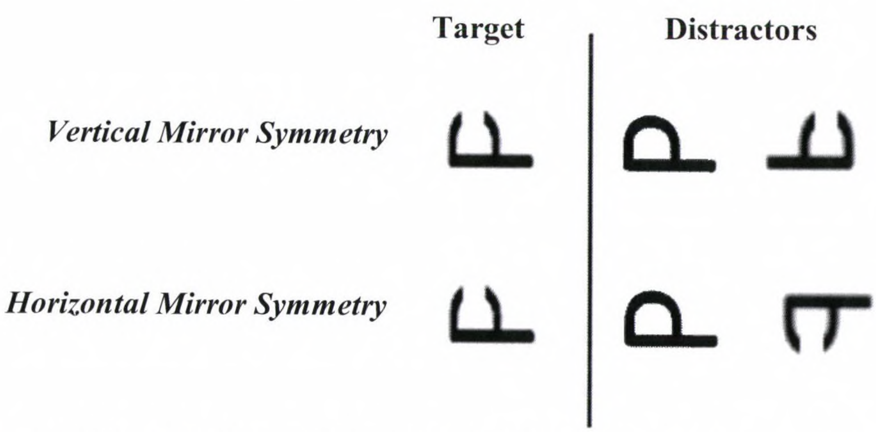


Figure 16. Stimuli used in the Roggeveen et. al. (2004) study. The target was presented with an equal number of both types of distractors. However, the target clearly shares mirror symmetry with the second distractor type in both conditions.

However, questions remain about the processes underlying configural asymmetries effect (Exp. 1) and the contributions of mirror symmetry and left/right versus up/down judgments to the original effect. The inherent question is whether configural asymmetries are based solely on mirror symmetry, left/right versus up/down decisions, or perhaps as a combination of both processes.

In general, the results support that configural asymmetries are driven by both processes. These conclusions are drawn largely from comparisons of the results between the first and second experiments. Comparisons between these experiments are ideal since the studies shared similar methodology except for how the stimuli were bisected: Exp. 1 stimuli were split horizontally and vertically supposedly creating a condition in which both left/right versus up/down judgments and mirror symmetry contribute to search, whereas Exp. 2 stimuli were bisected obliquely which isolated mirror symmetry.

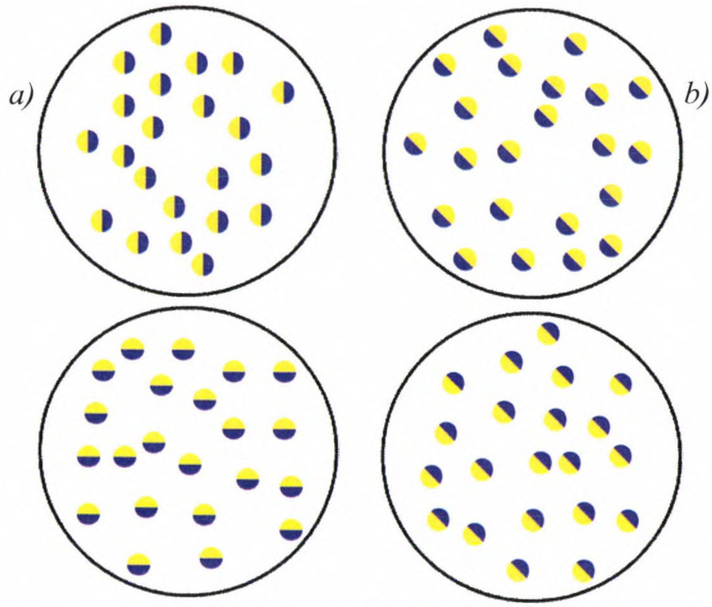


Figure 17. Example target absent displays for the first and second experiments. The left hand column demonstrates displays for the first experiment in which elements were bisected horizontally and vertically. The right hand column demonstrates displays for the second experiment in which stimuli were bisected at a 45° angle.

One point of interest, which perhaps affirms this interaction between the Object Region Account and Inter-item Symmetry Account, is the difference in effect size for the target present data between the first and second experiment. In the second experiment, an effect size ≈.205 was obtained compared to a larger effect size ≈.932 found in experiment one; although effect size measures do not distinguish whether these differences are due to larger differences in the means or variance terms. A better way to illustrate these differences is to compare the magnitude of the asymmetry- calculated as the ratio of performance for vertical displays over performance for horizontal displays (Monnier et. al., 2010). With magnitude estimates, ratios over 1.00 represent instances where vertical conditions are searched through more slowly than horizontal conditions; ratios below 1.00 represent the opposite effect. Calculation of these magnitudes showed a larger search difference in experiment one compared to experiment two. The magnitude of the asymmetry found in experiment one was ≈1.37 meaning that on average vertical displays were searched through 1.37 times more slowly than horizontal displays. In the second experiment, the magnitude was much smaller approaching ≈1.07 – vertical displays were searched on average 1.07 times slower than horizontal displays. These calculations demonstrate that the differences between the two experiments were in part due to large changes in the differences of the means between the two experiments: a much larger shift was noted for Exp. 1 compared to Exp. 2.These differences are hard to explain if we assume mirror symmetry as the sole process involved in configural asymmetries. If this were the case, one would expect effect sizes in both experiments to either be equal or perhaps larger in the second experiment given mirror symmetry was present in both experiments but there was no interference of left/right and up/down judgments for the second experiment. However, the results do not justify this line of reasoning. The results obtained actually exhibited an opposite pattern –larger effect sizes were found in the first experiment than in the second. These results support that configural asymmetries are driven by two separate processes which co-occur: both the processing of mirror symmetry relationships and judgments across regions of individual objects.

Other evidence supports the interaction of these two processes. One important observation the authors noted was different outcomes for target absent data between the first and second experiment. In the first experiment, a clear difference in target absent trials was found with vertical displays being more difficult than horizontal displays (the magnitude of this asymmetry was $\approx$1.20). However in the second experiment, these differences failed to replicate and actually showed an opposite effect (the magnitude of this experiment was $\approx$.95). If configural asymmetries were solely about processing mirror symmetry one would expect no differences in either experiment since none of the target absent trials contained mirror symmetry (compare the four conditions in Fig. 17). The authors reconcile these differences between target-absent data as the unique influence of left/right versus up/down decisions in search. Note how only the left-hand displays of Fig. 18, representing conditions from the first experiment, require left/right versus up/down judgments whereas the right-hand displays, representing the conditions of the second experiment, do not. This difference is perhaps what drove the effect for the first but not second experiment indirectly supporting the Object-Region Account and the contribution of left/right versus up/down comparisons within objects to visual processing.

The findings of this report also underscore the inefficiency of humans in visual search tasks. In experiments two and three, an ideal observer would remain agnostic towards mirror symmetry and locate the target by considering only the orientation of the line segment formed by the abutting colored regions. For instance, in experiment two, the target could be reliably distinguished from distractors as the element with a line segment rotated -45° away from vertical while the distractors where all +45° from vertical (refer to Fig. 7). Likewise, in experiment three the target could be readily identified as the only element whose line segment is not positioned obliquely. However, the results show that participants were influenced by mirror symmetry relationships even when this information was irrelevant, or less than ideal, in identifying the target. One possible explanation for the difficulty of these searches is that the target's orientation was not linearly separable from orientation of the distractors. In other words, for experiment three, the orientation of the target lay in an intermediate position (0° or 90°) between the oblique positioning of the distractors (-45° and 45°) shown in Fig. 18. Finding targets that are not linearly separable from distractors along a given dimension has been shown to produce difficult search tasks (Wolfe, Friedman-Hill, Stewart, & O'Connell, 1992; Bauer, Jolicoeur, & Cowan, 1996; Hodsoll and Humphreys, 2005) and perhaps made search more difficult in these studies and reduced participants' ability to develop more efficient search strategies.

Overall configural asymmetries and the study of their underlying processes, specifically the effects of mirror symmetry on grouping, are intriguing. Given the outcome of the present studies, previously unexplained configural asymmetry effects appear to be driven by an interaction of mirror symmetry relationships between objects and judgments along various regions within individual objects. Also, the present results demonstrated the strong probability that mirror symmetry engages grouping processes in visual processing. To date, neither mirror symmetry nor the effect of making judgments along various regions of an element have been implemented in any contemporary theory of object perception – which may be due, in part, to a limited understanding of these two processes until recently. While admittedly this report is not sufficient in providing such a full explanation of the two processes, it does provide strong and consistent evidence that both mirror symmetry and left/right versus up/down judgments produce reliable differences in search performance. Therefore the authors will try to attempt to integrate these findings within current frameworks of object perception.

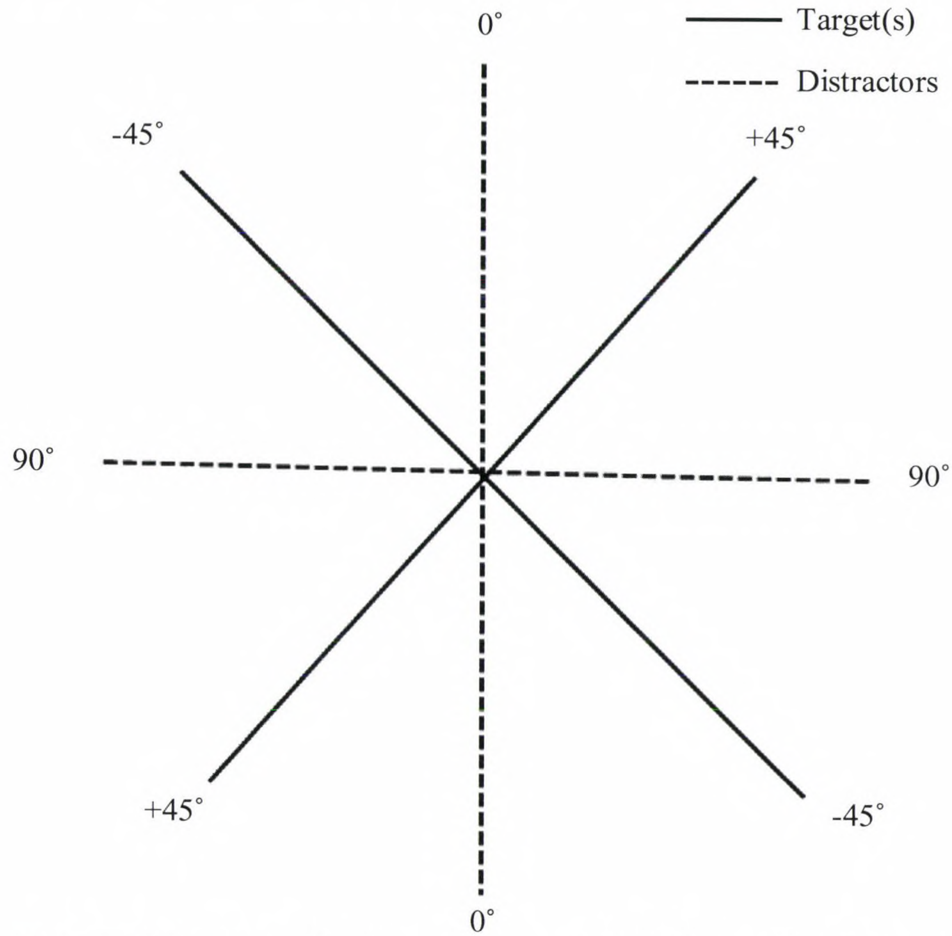


Figure 18. A graphical representation of the non-linear separability of targets from distractors in the third experiment. Dashed lines represent the vertical (0°) and horizontal (90°) targets. Solid lines represent the two distractor groups oriented obliquely (+45° and -45°). The orientation of both target types lay in an intermediate space between the distractors contributing to the difficulty of the task.

Let us first address how left/right versus up/down judgments might be implemented in theories of object perception. Incorporation of left/right versus up/down judgments into current views of object perception can be done relatively simplistically. By in large, most theories of object perception agree upon an initial parallel extraction of information across various independent visual dimensions. Reconciling these object-based effects could be achieved simply by applying a bias in the spatial processing of information which favors the up/down regions of an object over the left/right regions during extraction (Monnier et. al., 2010). This biasing across the regions of an object would result in reduced saliency towards information coming from the horizontal ("left/right") regions compared to vertical ("up/down") regions within an element. This is a simplistic yet plausible approach but it is not without criticism about it generalization to other stimuli. One question about the influence of conducting judgments across regions of an object is whether these effects can be reproduced using asymmetrical stimuli. If, as the Object Region Account argues, difficulties in said processing arise due to the prevalence of vertical mirror symmetry and the redundancy in the left/right domain, then would these effects occur when processing asymmetric objects whose left/right regions are not inherently the same and therefore might yield potentially useful information about the object? Though these results indirectly support the Object Region Account, there is a need to directly test this account under a variety of other search conditions including processing of asymmetric stimuli.

Next, let us consider how mirror symmetry fits within current models of object perception. Mirror symmetry, as investigated in this report, was an abstract and complex spatial relationship held between multiple objects positioned throughout the visual field. Such complex spatial relationships are difficult but not impossible to accommodate in serial-processing theories of object perception. Serial-processing theories propose that information across various dimensions is only aggregated or compared within very limited spatial regions and during an attentionally demanding serial stage of processing. Feature Integration Theory (Treisman and Gelade, 1980; Treisman, 1993) is an example of a serial theory. A possible reconciliation for these findings and theories like FIT is that perhaps the visual system processes mirror symmetry along some feature dimension between elements. Although, given the complexity of the present experiments, what feature dimension that might be procured to encode mirror symmetry is not readily apparent and definitely not derived from a simple geometric property. Alternatively, it has been proposed by serial models that perhaps these differences are best understood as the selective inhibition of a set group of elements sharing a common feature with the target. However, selective inhibition is not a likely account given the continually altering target and distractor characteristics between trials which ought to negate "top-down" influences on search.

Mirror symmetry is perhaps better understood as a dimension influencing grouping (Rogeveen et. al., 2004; Van Zoest et. al., 2006). Grouping was crucial to Duncan and Humphreys' Attentional Enagement Theory and their model provides a suitable explanation to the results collected within this report Support for mirror symmetry being considered a dimension of grouping was demonstrated in the differences in search performance when mirror symmetry was isolated from left/right and up/down decisions and the consistency of results when mirror symmetry was held between target and distractors and between groups of distractors. Therefore, the authors propose that mirror symmetry is a principle dimension in which grouping occurs and can be incorporated into the Attentional Engagement Theory as a dimension that directly influences weighting within the *weight-linkage* map.

Finally, though not in the nature of serial models of object perception such as FIT, one could make a case for a hybrid model of visual perception combining the concept of "feature" coding and the effect of grouping. Though sacrificing parsimony, this hybrid theory offers possible reconciliation between this report and traditional serial models of object perception. In such a hybrid model, one could assume that the parallel extraction of information is accompanied by secondary extraction of information along dimensions of grouping. Grouping information is combined with feature information either initially at extraction or perhaps in subsequent stages of serial inspection. Perhaps grouping information weights the importance of information present within feature maps. This combined information guides and directs our behavior during visual inspection. With this understanding, perhaps mirror symmetry is not a "feature" coded for by the visual system but instead is one of the dimensions of grouping extracted from the visual scene.

These reports are far from complete in answering all the questions regarding mirror symmetry and grouping. Additional questions addressing mirror symmetry still need to be answered. One important question is how mirror symmetry between elements is encoded by the visual system? There is already a good understanding as to how symmetry across a display is encoded but no direct answer as to how symmetry between objects is coded. Future reports should focus on explaining how mirror symmetry between elements is extracted and which mechanisms and processes are involved in such a task.

Furthermore, mirror symmetry appeared to have a less pronounced effect when held among groups of distractors in comparison to when mirror symmetry was held against target and distractors. This raises considerable questions as to the nature of grouping and how mirror symmetry is processed by the visual system. Are the effects of mirror symmetry larger when held between target and distractors because symmetry is being evaluated twice by the visual system but only once when held among distractor (Roggeveen et. al, 2004)? Roggeveen and colleagues offered the explanation that target - distractor mirror symmetry might be processed first during the initial extraction of information and secondly when individual elements are compared to a mental representation of the target held in visual working memory, whereas mirror symmetry between distractors is only processed in the initial extraction of information. Since mirror symmetry is evaluated twice when held between target and distractors then it would have a larger effect on performance. Future studies should investigate these effects and try to understand the time course in processing mirror symmetry, whether it occurs pre-attentively, following the deployment of attention and comparisons of elements to mental representations of the target, or perhaps in both stages.

Alternatively, the authors have questions about mirror symmetry's effect across various spatial scales. Currently, mirror symmetry in visual search has only been investigated between individual elements and not as a relationship between configurations of elements. For example, is search for a target defined by color influenced if search elements are arranged into mirror symmetric configurations? Such an experiment would address whether mirror symmetry produces differences in search performance even when it is not task relevant and might also provide answers as to the interplay of grouping against various dimensions occurring at different spatial scales.

Finally, this report highlights the importance of two concepts when conducting visual search experiments. First, when investigating new visual search phenomena, such as configural asymmetries, it is critical to understand that multiple processes can be involved in a singular visual search event. For configural asymmetries, strong evidence has been provided contesting that both mirror symmetry between objects (context-based process) greatly influences search performance and, to a lesser extent, the results support decisions across left/right regions within an object (object-based processes) are harder to make than comparisons across the up/down regions. On the surface, these conclusions provide support for Object Region Account and Inter-item Symmetry Account but in a much broader scope provide caution to vision researches trying to define new effects in visual search. Secondly, this highlights the importance of studying visual processing both in terms of target-distractor relationships and of distractor relationships themselves which have been shown within this report to influence performance differently. Testing distractor relationships admittedly requires a more complex experimental design; nonetheless, understanding distractor relationships are crucial to gaining a better understanding of the processes in visual perception and have been shown to be important within this report.

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