The role of convexity in the corner enhancement effect, in visual short-term memory, in perception of symmetry, and in shape interference

2012

A thesis submitted to the School of Psychology University of Liverpool for the degree of Doctor of Philosophy in the Faculty of Health and Life Science

May Salah Helmy

School of Psychology

University Of Liverpool

Phi Beta Kappa

Φιλοσοφία Βίου Κυβερνήτης or *philosophia biou kybernētēs*

"Love of learning is the guide of life"

Contents

List of tables

List of figures

List of abbreviations

ANOVA	Analysis of Variance
C'	Normalised criterion C. A measure of response bias
D’	D Prime. A measure of sensitivity
2D	Two dimensional
3D	Three dimensional
EEG	Electroencephalography
FA	False alarm
fMRI	Functional Magnetic Resonance Imaging
H	Hit rate
LOC	Lateral occipital complex
M	Mean
Msec	Milliseconds
P	Probability
RT	Reaction time
SD	Standard Deviation
SDT	Signal detection theory
SPSS	Statistical Package for the Social Science
VLTM	Visual long-term memory
VSTM	Visual short-term memory

ABSTRACT

Contour curvature information has been shown to have an impact on the visual perception of shape. We have conducted studies on perception of convexity and concavity in relation to memory and attention.

Previous studies (Badcock & Westheirner, 1985; Krose & Julesz, 1989; Nakayama & Mackeben, 1989) have proposed that visual space is influenced by corners. Recent studies by Cole, Burton and Gellatly (2001) found that reaction times were faster for a stimulus located in the region of a corner of a figure. Cole *et al* (2001) believe that the role of corners is greater than that of straight edges, due to corners receiving a higher distribution of attentional resources relative to straight edges. The first part of this thesis considers the role figure-ground plays in the corner enhancement effect. Results demonstrate that the corner enhancement effect is only found when the probe is presented on the surface that owns the corner. Thus the corner enhancement effect is present for both concave and convex vertices. However, the effect disappears when the probe lay on the surface that does not own the corner.

The second series of experiments made use of a shape with multiple concave or convex features as part of a change detection task, in which only a single feature could change. The results provided no evidence to suggest that convexities are special in visual short-term memory. Though coding of convexities as well as concavities provided a small advantage over an isolated contour. This finding is in accordance with the well documented effect of closure on shape processing (Elder & Zucker, 1993).

It has been reported that deviations from symmetry were easier to detect when carried by convexities compared to deviations carried by concavities (Hulleman & Olivers, 2007). We extended this investigation to shapes that were repeated instead of reflected, to test whether there is a specific convexity advantage for bilateral symmetry. The results supported a convexity advantage for repetitions but not for reflections. Possible explanations for this are discussed.

The final series of experiments involved a shape interference task; observers responded to circles or square in the context of irrelevant circles and squares. The findings suggest that interference between the shapes is much stronger when the contours that define the shapes belong to the same surface.

In summary, we conclude that convexity and concavity are important aspects of shape analysis and representation, but there is no basic difference in how convexities and concavities are attended to, both in the corner enhancement effect, and in visual-short term memory. However, convexity plays a role in some perceptual tasks for example, when analyzing complex shapes observers may adopt strategies that focus on the convexities.

Declaration

No portion of work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other University or institute of learning.

Copyright statement

Publications

Parts of this thesis appear in other publications by Mai salah helmy and colleagues:

Bertamini, M. Helmy, M.S., & Hulleman, J. (2012). The role of convexity in perception of symmetry and in visual short-term memory. DOI:

Bertamini, M., & Helmy, M.S. (2012). The shape of a hole and that of the surface – with-hole cannot be analysed separately. Psychonomic Bulletin & Review.

Helmy, M.S., & Bertamini, M. (2012). The role of figure ground in corner enhancement effect (in preparation).

Published Peer-review Abstracts

Bertamini, M. & Mohamed Helmy, M. (2012). Attention allocation to regions perceived as holes. ECVP meeting, Italy, September 2012.

Mohamed Helmy, M. & Bertamini, M. (2011). The role of figure ground in the corner enhancement effect. AVA meeting, York, December 2011.

Mohamed Helmy, M. & Bertamini, M. (2010). VSTM for convexities and concavities along a single contour. AVA meeting, Paris, December 2010. Perception, 40.

Mohamed Helmy, M. & Bertamini, M. (2010). Convex and concave parts in visual short term memory. AVA meeting, Liverpool, March 2010. Perception, 39.

Bertamini, M. Mohamed Helmy, M., Skarratt, P.A., & Cole, G.G. (2009). Corner enhancement effect: comparing convex and concave corners ECVP meeting, Regensburg, August 2009. Perception, (Suppl.).

Acknowledgements

I have many people to thank for their support during the production of this work, most notably my supervisor Dr Marco Bertamini and co-supervisor Dr Rebecca Lawson. Marco has provided encouragement and wise counsel, and this manuscript has benefited from his many helpful comments and great clarity of mind. He has dedicated a remarkable amount of his time and energy towards developing me since I came from Egypt. Likewise, Rebecca has provided a great amount of help and support throughout the production of my thesis, for which I am truly grateful.

I also express my gratitude to the people who volunteered their time to participate in my experiments. Without their good nature and patience, this thesis would not have been possible.

At the University of Liverpool I have enjoyed the opportunity to collaborate with my colleagues, in lab meetings and during work. I would like to thank all of them for their valuable comments and evaluation of our ideas and presentations.

Finally, I would like to mention my parents for their endless provision of support. I would particularly like to give a dedication to the soul of my mother and my father, and hope they are here at this moment.

CHAPTER 1| Introduction

1.1 The problem of convexity and concavity:

This thesis investigated the difference between convex and concave regions of a contour in a simple detection task, in visual short-term memory and in perception of symmetry and shape interference. In this introduction the role of convexity and concavity along a contour in visual perception is described.

Humans are able to easily detect and recognize objects using vision, in spite of the multiple complexities and uncertainties of the visual world. One of the most salient sources of information that helps observers to recognize the shape of objects is the shape of contours. They convey information about the visual environment and the shape of objects (Hoffman & Richards, 1984; Hoffman, 2000; Bertamini, 2008). In two–dimensional shapes (2D) the curvature of a contour can be analyzed and it is possible to distinguish between either convex regions (positive curvature) or concave regions (negative curvature). The former (convex region) refers to a protrusion outward of an object, whereas the latter (concave regions) are indentations (inside) of an object (see figure 1.1) (Hoffman& Richards, 1984; Hoffman & Singh, 1997; Bertamini& Croucher, 2003; Bertamini, 2008; Barenholtz, Cohen, Feldman, & Singh, 2003).

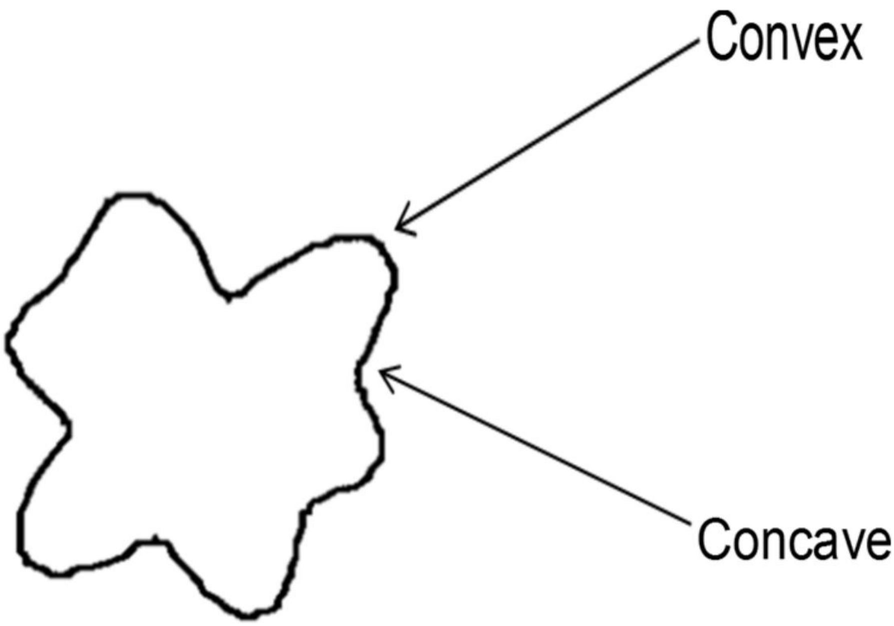


Figure 1.1.A contour illustrating the presence of convex and concave regions.

The terms convexity and concavity can be used in relation to 2D contours or 3D surfaces. Two literatures exist, one focusing on 2D and one on 3D. For example, Langer and Bulthoff (2001) have found a convexity advantage in local shape from shading in a three-dimensional (3D) task (Langer & Bulthoff, 2001). In my thesis we will focus on the role of convexity and concavity along a contour in two-dimensional shapes (2D).

Within 2D shapes there is also an important distinction between local and global convexity/concavity. In terms of global convexity, by definition, any closed polygon that is not strictly convex is called concave (see figure 1.2), and a strictly convex polygon is one with no internal angle greater than 180 deg. To distinguish whether an object is convex, mathematical definitions can be used:

- A straight line connecting any two points and not passing the curve at any point.
- The curve having no change of curvature and having the similar effect.
- The curvature having the same sign.

Following these rules, an object is convex if for any two points within the object, any point lying on the line that joins them also lies within the object, for example a square is convex, but any object which contains a dent is not (Hoffman, 2000). Consequently, considering Figure 1.2., the concave polygon (the green example) has one region on the top with a concavity and a region at the bottom; a convexity. The convex polygons have only convexities. However, instead of using this definition, which applies to polygons, we will refer to local convexity and concavity which applies to locations along a contour.

The amount of curvature along a smooth closed contour can be measured. The contour can curve more or less, but it can also curve in two different ways. This difference can be coded by positive or negative curvature (convex region and concave region). In figure 1.2 on the left we have both concave and convex regions, whereas on the right we have convex regions only.

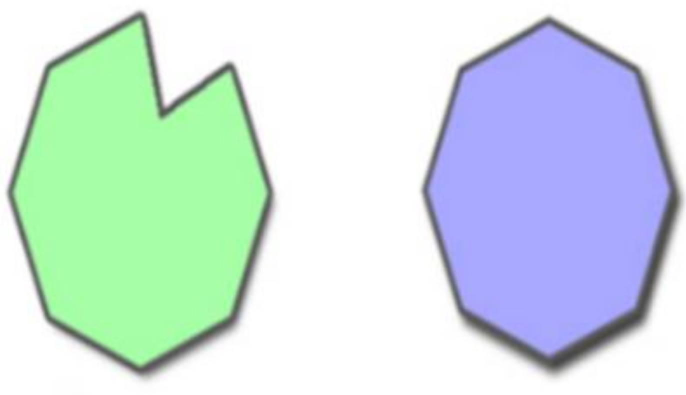


Figure.1.2.Examples of local Convexity and Concaveity in two dimensional shape (2D). The local concavity is one of the vertices on the green example, and there is no local concavity along the whole contour on the blue example.

In three-dimensional shape (3D) there are three types of surfaces based on curvature: convex, concave and saddle. Figure 1.3 provides an example of a solid shape with convexities and saddle regions. On the left we have both convex regions and saddle regions (the green example), whereas on the right we have convex regions only (the blue example).

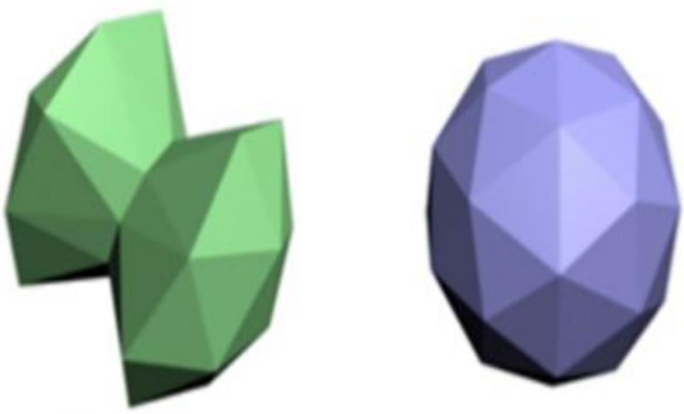


Figure.1.3.Examples of 3D shapes with local convex and saddles regions. The saddle surface is along the crease on the green example (one direction of curvature is concave and the other direction is convex) and there are only convexities along the whole surface on the blue example.

Koenderink (1984) analysed the situation where the 2D contour may be the projection of a 3D object. This means the concave contour in 2D is not the projection of a concave surface, but that of a saddle surface and the convex contour in 2D is the projection of a convex surface (Koenderink, 1984; Koenderink & Van Doorn, 1982). In this thesis we will focus on visual processing of 2D convexity and concavity.

The evidence of differential levels of performance for convexity and concavity is mixed. Barenholtz, Cohen, Feldman, and Singh (2003) have reported a difference on a detection task with an advantage for detection of concavity, but when other factors were eliminated, similar levels of performance were found (Bertamini, 2008; Bell, Hancock, Kingdom, & Peirce, 2010). However, a privileged coding of convexity (higher sensitivity in Lateral occipital complex (LOC) has been reported in a recent Functional Magnetic Resonance Imaging (fMRI) adaptation study (Haushofer, Baker, Livingstone, & Kanwisher, 2008). Convexities have also been found to be more important in a symmetry detection task (Hulleman & Olivers, 2007).

Shape is highly influential in human object perception (Biederman, 1987; Hoffman & Richards, 1984; Hoffman, 2000). For example, Saiki and Hummel (1998) suggested that object recognition has two stages: firstly the visual system divides images into their parts; in the second stage, the parts transfer to the memory for recognition. So, our understanding of visual perception helps us to construct everything we see in our visual world: for instance, colour, shading, shape, and visual objects (Hoffman, 2000).

It is possible that understanding shape requires constructing parts. Parts are useful for recognition for two reasons: firstly we are not able to see through most objects because they are opaque; one can see the front of an object but not its back; secondly many objects can be changed or adapted. Consequently, some researchers (Biederman, 1987; Cave & Kosslyn, 1993; Hoffman & Singh, 1997; Hoffman & Richards, 1984; Singh, Seyranian & Hoffman, 1999; Lamote & Wagemans, 1999; Van Lier & Wagemans, 1998) have demonstrated that participants parsed objects in parts using various criteria (De Winter & Wagemans, 2008). This gives us a stable idea of objects and an efficient index into our memory for shapes (Hoffman, 2000; De Winter & Wagemans, 2008).

Parts play an important role in object representation, such as visual search, attention, memory and any visual functions (Hoffman &Richards, 1984; Singh & Hoffman, 1998; De Winter & Wagemans, 2008; Hayden et al., 2011). Bertamini and Lawson (2008), Rosin (2000), Singh and Hoffman (1998) have concluded that parts play a fundamental role in perception of objects (De Winter & Wagemans, 2008; Hayden et al., 2011).

1.2 Curvature as a basic feature

Contour curvature has been the subject of considerable research and investigation, and there is broad consensus that the magnitude (i.e. the sharpness of a curve) and sign of curvature are essential aspects of shape representation (Hoffman & Richards, 1984; Dobbins et al., 1989; Wolfe, Yee & Friedman-Hill, 1992).

In visual search tasks, participants are asked to search for a target among distracter items; the efficiency of a search task depends on the nature of the target and the distracter items. In this context, a "smooth contour" can be defined as a contour where orientation is changing continuously. Curvature is an essential visual element which supports visual search. The role of curvature can be measured in both two-dimensional (Treisman & Gormican, 1988) and three-dimensional shapes (Enns & Resink, 1990).

Tresiman and Gormican (1988) have demonstrated that curvature is a primary feature, and that the visual search for a curve among straight edges is very efficient, while in contrast the search for straight edges among curves is comparatively less efficient. Results from several studies (for example, Wolfe et al., 1992) confirmed that a curved target can be found efficiently among straight edges in a visual search task.

Wolfe et al., (1992) demonstrated that curvature is an essential feature in visual search; the effect of curvature was found to depend on the sign of curvature (concave or convex). They asked participants to detect curves among a straight edge, and in some trials they asked them to detect, for example, right curves among left curves. Their experiments explored variations within the visual search paradigm, and concluded that curvature is a fundamental feature of the visual search process (Wolfe et al., 1992).

The role of contour curvature magnitude in shape perception was recognised as long as 1000 years ago (11th century), when Medieval Iranian mathematician and physicist Alhazen researched and detailed the importance of the concavities and convexities of an objects boundary contour in shape perception: “... for sight will perceive the figure of the surfaces of whose parts have different positions by perceiving the convexity, concavity or flatness of those points, and by perceiving their protuberance or depression”, Normans, Phillips, & Ross, 2001, p.1285). Furthermore, Rittenhouse (1786) as discussed in Howard(1983) argued that the ability to determine the convexity or concavity of a surface is dependent on the distribution of luminance and shade over that surface, naming this phenomenon the ‘matrix patrix’ phenomenon. Rittenhouse contended that when luminance (i.e. the perceived source of light) comes from above, the feature in question would be seen as convex, but would be conversely perceived as concave if the source of illumination came from below (as discussed in Howard, 1983). Almost 200 years later, Attneave (1954) argued that the curvature of contour is the most important source of information in the perception of shape. His argument was illustrated with his famous ‘Attneave cat’, an example in which only the points of high curvature are joined to create a drawing of a cat.

Figure 1.4. The famous example of an outline of a cat using only straight lines (Attneave, 1954). This Attneave cat is illustrated the points of high curvature on a drawing of a cat and connecting them by straight lines.

Hoffman and Richards (1984) suggested that the visual system uses the negative minima of curvature in concave regions along a shape-occluding contour to define boundaries between contour parts. Parts at negative minima have been found to explain a number of phenomena in shape perception (Singh & Hoffman, 2001), including the perception of symmetry (Baylis & Driver, 1994), changes in perceived shape associated with figure and ground (Driver & Baylis, 1994; Hoffman & Singh, 1997), the perception of transparency (Singh & Hoffman, 1998), visual search asymmetries (Hulleman, Winkle, & Boselie, 2000; Wolfe & Bennett, 1997; Xu & Singh, 2002), differential performance in comparing two probes along a shape outline (Barenhlotz & Feldman, 2003), object priming (De Winter & Wagemans, 2008), and change detection involving complex shapes indicate a heightened sensitivity to concavities (Barenholtz et al., 2003; Cohen, Barenholtz, Singh, & Feldman, 2005).

It has been argued that the visual system perceives shapes as composed of parts, which are separated by minima of curvature (Hoffman & Richards, 1984; Bertamini & Croucher, 2003). This is a rule for dividing visual shapes into units and surface into parts at convex and concave regions. The rule divides surfaces into parts at high curvature points on the surface. Therefore, Hoffman and Richards (1984) used two rules to divide a surface into parts:

- Divide a surface into parts at a concave region.
- Divide a surface into parts at local of negative minima of each curvature (the minima rule).

The minima rule was developed by Hoffman and Richards (1984, see also Beusmans & Bennett, 1987, and Braunstein, Hoffman, & Saidpour, 1989). According to the minima rule, human vision defines part boundaries at negative minima of curvature on silhouettes, and along negative minima of the principle curvatures on surfaces

(Hoffman & Richards, 1984; Hoffman & Singh, 1997; Fantoni, Bertamini, & Gerbino, 2005; Cohen & Singh, 2006; Barenhlotz & Feldman, 2006; Vandekerckhove, Panis & Wagemans, 2007; Cohen & Singh, 2007; Cate & Behrmann, 2010).

Braunstein et al. (1989) hypothesised that test participants perceptually divided objects into parts at the negative minima of curvature and at the positive maxima of curvature, and their results indicated that participants were performing more easily at negative minima, compared to stimuli divided at positive maxima. Therefore, 81% of participants marked part boundaries at negative minima, and were choosing negative minima rather than narrow points as part boundaries (Braunstein et al., 1989). These results were consistent with the findings of Biederman's study (1987) which demonstrated that objects tend to be divided at regions of concavity; region division and recognition was impaired when contours were hidden or deleted at a region of concavity rather than at a region of convexity (Biederman, 1987).

We will discuss now the importance of concave regions in some different tasks.

1.3 The importance of concave regions

The importance of convex regions and concave regions is debated in the literature. Some researchers (Barenholtz et al., 2003; Cohen et al., 2005) have proposed that concavity plays a more important role than convexity in shape perception. Concave vertices can be easily detected in visual displays (Hulleman, Winkel, & Boselie, 2000; Humphreys & Muller, 2000). For instance, the search for a concave target among convex stimuli is more efficient and accurate than the search for a convex target among concave stimuli (Hulleman et al., 2000; Humphreys & Muller, 2000; Wolfe & Bennett, 1997; Bhatt et al., 2006).

In a further example of the importance of concavity, Humphreys and Muller (2000) demonstrated that participants were able to accurately detect changes for a concave target among convex distractions than the search for a convex target among concave distractions. Even when the figure and background stimuli were both reversed, participants could still detect changes to concave regions. They found that when the contour was perceived to belong to a concave region it proved quicker and easier for participants to detect changes, compared with contours perceived to belong to a convex region.

Moreover, the literature suggests that the visual search for a concave target among convex distractions is faster than the search for a convex target among concave distractions. In their experiment, Humphreys and Muller based their work on Hoffman and Richards' (1984) contention that concave edges occur at part boundaries, whereas convex edges occur within parts. This is consistent with the findings of Elder and Zucker (1993), who argued that search for a concave target, is more efficient than search for a convex target (Elder &Zucker, 1993).

This is consistent with the findings of Barenholtz et al., (2003), who argued that any change to the curvature-sign of a contour is easily detected when that change belongs to a concave region rather than a convex region. In their study participants were asked to decide when a polygon stimulus changed shape from the first interval to the second interval. Interestingly, differences in participant responses could be accounted for by the change or removal of a concavity, which often changed the part structure of the shape. On the other hand, changing or removing a convexity often left the parts of the structure the same, without any perceived change.

There is substantial evidence in research literature to support the important role of concavity in the perception of part structure. Bertamini and Lawson (2006) demonstrated that concavity plays a salient role in part structure, albeit to no greater extent than the role of convexity. This is not because the concavity itself plays a central role in determining perceived part structure, but rather because it helps the viewer to divide the complex regions into parts (Bertamini & Lawson, 2006). Bertamini and Lawson asked participants, through a series of experiments, to detect changes to both concave and convex conditions (with convex regions perceived as figures and concave regions as holes). They tested the hypothesis that it is easier to search for a concave region among convex stimuli in comparison with the search for a convex region among concave stimuli, but did not find a difference.

Moreover, reaction times (RT) were found to be faster for concave targets than convex targets (Hulleman, Winkle, & Boselie, 2000). They asked participants to detect the target (in half of the trials, the target is the concave region; in half the target is the convex region) as quickly as possible among distracters. The presence of a concave target among convex distractions appears to be more salient than the presence of a convex target among concave distractions. This is consistent with the findings of Wolfe and Bennett (1997) who reported that the search for a target with concave regions among convex distracters was efficient, whereas the search for a target with convex regions among concave distracters was much slower (Hulleman et al., 2000).

Koenderink (1990) concluded that concavities are important for shape parsing, and concavities in particular are more significant for an early and obligatory process of parsing (Bertamini, 2008, Barenholtz, & Tarr, 2009, Barenholtz, 2010). Moreover, participants have been found to be more sensitive to change in shapes when the change occurs within a concavity rather than a convexity (Cohen et al., 2005). This study contradicts that of Baylis and Driver (1995) in one important point; in their study (2005), Cohen et al. designed a test which involved participants detecting changes across two presentations of an entire shape, whereas Baylis and Driver’s study required matching a shape fragment to an entire shape. This resulted in mild sensitivity to convexity for Baylis and Driver, but in the case of Cohen et al., resulted in high sensitivity to concave corners, not because concavities are the basic units of shape perception, but rather because concavity plays an important role in outlining basic features in the perception of shape (Cohen et al., 2005).

In conclusion, from these visual search and change detection investigations we can establish that concavity plays a salient role in the perception of shape, and furthermore that its salience is intrinsically related to its role in part structure.

1.4 Convexity Advantages

It has been argued by many (Gibson, 1994; Bertamini, 2006; Bertamini, 2008; Bertamini, 2001) that the location of a convex region is easier to judge than the location of a concave region. This is for two reasons. Firstly, convex regions communicate more information than concave regions about the overall structure of a shape (Bertamini, 2001). Secondly, convex regions are perceived as more organised as structures than concave regions.

Convexity plays an important role in perceptual organization. It is a robust and efficient perceptual grouping cue, and provides a range of information about perceptual grouping to a greater extent than any other cue. Symmetry is a good example of one such additional cue, and this is confirmed by the results of several studies, including Kovacs and Julesz (1993).

Kanisza and Gerbino’s 1976 study was the first experimental study to support the importance of convexities in figure-ground organisation. Furthermore, the idea that convex regions are perceived as a figure, rather than ground, has been discussed over many years by Rubin (1915) and Kansiza and Gerbino (1976). Treisman and Gormican (1988) went on to demonstrate that curved contours were more easily recognised than straight edges, apparently due to the fact that straight edges are less informative.

In the literature, contour regions where the curvature of a figure changes contain more information about the shape than regions where the curvature is uniform (Kristjansson & Tse, 2001). Tests prove easier for participants when they perceive the convex shape as a figure, and responses are faster in recognising the figure which they perceive as convex. For example, in Kansiza and Gerbino's study, in the case of 73 out of 80 participants the convex areas in the test stimuli were perceived as a figure (Kansiza & Gerbino, 1976).

Moreover, these results are consistent with those of Hoffman and Richards (1984) who concluded that convex features are peculiarly significant in a visual context (Pasupathy & Connor, 2001; Braunstein, Hoffman, & Saidpour, 1989). This observation is backed up by the findings of numerous researchers (including Hoffman & Singh, 1997; Stevens & Brookes, 1988) in whose studies 90% of participants were more likely to see the figure as a convex and the background as a concave (Peterson & Salvagio, 2010).

These researchers have collectively demonstrated that convexity is a key factor in figure-ground perception because a convex region is more readily perceived as a part than a concave region (Bertamini, 2008; Bertamini & Lawson, 2008; Rosin, 2000; Pao, Geiger, & Rubin, 1999; Barenholtz, 2010). This conclusion was convincingly demonstrated by a task in which participants were faster in making perceptual position judgements for points belonging to the convex edge in comparison with the concave edge of a stimulus (Baylis, 1994; Liu, Jacobs & Basri, 1999; Wang, Stathl, Balley, & Dropps, 2007). In brief, figure-ground assignment plays a fundamental role in the perception of shape, and the concave regions are more readily perceived as belonging to an "empty" space (Barenholtz, 2010). So, Gestalt psychologists were the first scholars to demonstrate an interest in convexity as a factor in shape perception (Arnheim, 1954;

Kanizsa & Gerbino, 1976). Even with interactions from other grouping variables such as symmetry or size, a convex region is always perceived as foreground (Kanizsa & Gerbino, 1976). Convexity has also been demonstrated to increase response time to the presence of foreground regions even when the foreground shape is not pertaining to the task objectives (Bertamini & Lawson, 2008).

1.5 Practical applications of convexity

Convexity plays a central role in both human and computer vision. Numerous psychological research studies (Kanisza & Gerbino, 1976; Baylis, 1994; Liu et al., 1999; Bertamini, 2001; Kim & Peterson, 2001; Latecki & Lakämper, 1999) have shown that convexity has an influence similar to that of other factors such as closure, continuity and symmetry in human perceptual organisation. In addition, convexity is a key factor in detecting different kinds of cells in digital micrographs (Wang et al., 2007). Borra and Saker (1997) further argue that convexity has a special role in grouping and concluded that although the structure is not always convex; the convex grouping may provide more useful information which make convexity play a pivotal role in edge grouping (Borra & Saker, 1997, Wang et al., 2007).

1.5.1 The role of convexity when comparing two probes on the contour

Barenholtz and Feldman (2003) concluded that there is a strong indication that participants' performance is slower when they cross curvature minima (concavities) than maxima curvature (convexities), and that their performance improves when judging whether two probes on a contour remain the same or change (Barenholtz & Feldman,2003). Attention moves more easily within objects than between objects, and performance is faster when objects are perceived as belonging to the same units or objects than to different units or objects (Barenholtz & Feldman, 2003). They argue that convexity has a special role in visual comparison within and between object parts. In their experiment Barenholtz and Feldman compared the perception of two different types of changes to contour: these could be either within the contour (convex) or between objects (concave). Participants displayed faster reaction times using convex stimuli relative to reaction times using concave stimuli (Barenholtz & Feldman, 2003).

1.5.2 The role of convexity in the perception of symmetry

Convexity plays a central role in the perception of symmetry. Hulleman and Olivers (2007) investigated the relative importance of convexities (protrusions) and concavities (indentations) in the perception of shape. It has been suggested that convexities determine the shape of an object, whereas concavities merely act as "perceptual glue" between the convexities.

Participants find it easier to detect asymmetry in a 2-D silhouette when there is a mismatch between the shapes of convexities on either side of the axis of symmetry than when there is a mismatch between the shapes of concavities. This is the case even when the concavities are closest to the axis of symmetry, despite the usual bias toward this axis in symmetry perception (Hulleman & Olivers, 2007).

Hulleman and Olivers further suggest that the actual shape of concavities is less important in symmetry perception, because the main role of concavities is to act as part boundaries in the representation of the shape of objects. In other words, participants detected targets more easily in convex than concave regions, irrespective of their position relative to the axis of symmetry (Hulleman & Olivers, 2007).

1.5.3 The role of convexity in judging the position of convex stimuli

There is much evidence to support the important role of contour curvature in the perception of part structure. Bertamini (2001) reported that test participants were faster at judging the position of convex stimuli than concave vertices. Bertamini demonstrated that this result was due to the fact that convex vertices define parts of solid objects, and parts are perceived as having a position relative to the rest of the object. On the other hand, concave vertices are perceived as boundaries between parts. Consequently, positional information is more directly involved with convex than concave regions. This proves his experimental hypothesis that participants perform faster when judging the position of a stimulus arranged vertically in a convexity region, in comparison with stimuli arranged in other alignments. The central region of the test stimulus was divided into red (the figure) and green (the background); the position of the probe was in the top or in the bottom half of the figure and participants were asked to judge the position of the vertex along the base line. The results confirmed that it is easier to judge the position of a convex region than that of a concave region (Bertamini, 2001).

1.5.4 The role of convexity in visual short-term memory

One study has investigated the convex regions in VSTM. Sakai and Inui (2002) have shown that the limitation capacity of VSTM applies to convex parts (i.e. convex segments of a closed contour). They proposed a model of VSTM. Their study relies on a signal detection theory (SDT), and on dividing the contour into two regions: convex and concave. They tested the convex parts only. They used a stimulus which appeared for 360 msec, and disappeared for 720 msec, and finally reappeared. Subjects judged whether the first and the second presentation were the same or different. According to the authors, depending on the complexity of patterns, VSTM has a capacity of four convex parts and is retained in the memory more easily; and performance descended significantly as time exposure decreased. In consideration of these findings, it is reasonable to point out that the decay rate is weakened for longer exposure durations and the pre-eminent time to encode the features is 300 msec (Sakai & Inui, 2002).

Furthermore, retention of visual information became more easily when the curvature of the contour belongs to convex regions as opposed to concave regions and that retention of information applies to four convex segments (Sakai & Inui, 2002).

1.5.5 The role of convexity in depth stratification

Bertamini and Lawson (2008) contended that convexity plays a powerful role in depth stratification and concluded that participants demonstrate faster responses when the convex contour is perceived as a figure (perceived in the front plane in a stereogram) than when using concave contours (perceived behind). The test used a combination of convex-in-front versus concave-in-front stimuli, creating a disparity of the ground region: for half of the trials the convex side was positioned in front, and for the other half of the trials the concave side was positioned in front.

Participants were instructed to indicate which side of the region (the convex region or the concave region) appeared on the right or on the left side of the stimulus. The results clearly showed faster responses to convex-in-front stimuli and slower response to concave-in-front stimuli. Furthermore, the response to curved counters was significantly faster than to straight edges; reaction time (RT) for the targets belonging to the curved contour were faster compared to the targets belonging to straight edges (Bertamini & Lawson, 2008). Also, recognition performance and shape similarity were faster and more accurate for convex stimuli than concave stimuli (Haushofer et al. 2008).

1.5.6 The role of convexity in masking

There is much evidence in the research literature to support the important role of convexity in perception by masking. Poirier and Wilson (2007) have studied the role of the masking in convexities. Previous studies (for example Habak, Wilkinson, Zakher & Wilson’s, 2004; Hess, Wang, & Dakin, 1999) have investigated the role of the shape of the masking in both convexity and sides (concavity). Thus, these studies did not distinguish between the effects of the convexities and sides (concavities). Research results in this area are controversial due to methodological differences between each study. For example, Hess et al., (1999) used the mask contour at the location of convexity and sides and asked participants to discriminate shapes from circles (some of the circles were masked by obstructing the view of them, and others were left unmasked) in the test contour at the location of convex (curvature maxima) and sides (curvature minima). They concluded that masking was significant at both convex and concave regions (Hess et al., 1999). This is consistent with (Habak et al., 2004) study about the role of convexity in masking, which used another masking contour which could be located either inside or outside the test contour. The results of this study indicated that masking was significant when the test and mask shapes aligned, whereas no masking occurred when the convex area of the test contour was aligned with the sides of the mask contour (Habak et al., 2004). Conversely, Poirier and Wilson (2007) found that convexities provide stronger masking than concavities, contributing 58.9% of the shape masking effect. This study was based on a stimulus that contains convex contour and concave contour rather than corners or sides. They concluded that both convexities and sides make a significant contribution to masking, and that a convex contour is a prime source of information for shape processing, whereas sides have a smaller effect. These studies provide evidence to support the role of convexities and corners in object perception, and in supporting shape perception (Poirier & Wilson, 2007).

1.5.7 The role of convexity in perceptual grouping

Convexity plays a dominant role in perceptual grouping for example, symmetry, texture, and proximity. Numerous researchers (Kanizsa & Gerbino, 1976; Jacobs, 1996;

Liu, Jacobs, & Basri (1999) have proposed that good continuation and convexity play an important role in perceptual organization.

Liu et al., (1999) demonstrated for the first time the importance of convexity in perceptual completion. They used a new paradigm based on a stereo-acuity task, and through this new model evaluated the role of convexity in grouping, in order to determine whether or not convexity has good perceptual cues. Their experiments demonstrated that convex contours play a significant role in determining the strength of a model completion. Based on a series of experiments they concluded that the convex contour completion is grouped more efficiently than the concave contour. Therefore, we can confidently assert that convexity is a key factor in determining the strength of perceptual grouping (Liu et al., 1999).

1.5.8 The role of convexity in object representation

Haushofer, Baker, Livingstone, and Kanwisher (2008) demonstrated that convex contours play a salient role in cortical object representation. Their evidence suggests that convex vertices are coded in the lateral occipital complex (LOC), a region that has been implicated in object perception faster than concave contours.

Numerous researchers have argued that convex curvatures are more important than concave curvatures in the visual system. For example, Bertamini (2001) suggested that participants are more sensitive to a convex curvature rather than a concave curvature when judging the positions of convex vertex. Convex shapes are encoded in a privileged high level visual cortex, and as such the LOC is more sensitive to changes in convex than in concave shapes.

This is consistent with functional magnetic resonance imaging (fMRI) and electrophysiological studies. fMRI study has found higher sensitivity for convex vertices than concave vertices in the LOC. These studies underline the importance of convex stimuli in object-selective cortex (Vinberg & Grill-Spector, 2008). Electrophysiological studies (Pasupathy & Connor, 2001) have demonstrated stronger advantage and activation for convex versus concave shapes.

1.5.9 The role of convexity in shape from shading

Langer and Buithoff (2001) demonstrated that global convex shape plays a central role in shape from shading perception by using three dimensional shapes (3D). Participants did not use the non-shading cues (for example, occluding contours, shadows, perspective) when they decided to determine whether the stimulus surfaces were either globally convex, concave condition, or flat condition. They based their experiments on the *a priori* concept (such as illumination from above or viewpoint from above) that objects are globally convex, globally concave, or globally flat, and used a consistent source of illumination (from above). Participants were then asked to identify the local qualitative shape of isolated points on a surface.

Langer and Buithoff (2001) claimed that if test participants used the non-shading cues (occluding contours, shadows, and perspective) to determine if the surfaces were globally convex or globally concave, then performance using globally convex and concave stimuli were identical. On the other hand, if participants ignored the non-shading cues and depended on *a priori* knowledge then their performance improved using globally convex stimuli relative to globally concave stimuli (Langer & Buithoff, 2001).

1.5.10 The role of convexity in computer science

The study of convexity is important in disciplines including computer science, computer vision, and in the study of macaque neural area V4, as well as the study of symmetry, shading, judging position and probe discrimination. Some researchers claim convex surfaces have a tendency to be perceived as the "figure", in human visual perception. Figural organization is influenced more by convexity than other global shape properties, such as symmetry (Kanizsa & Gerbino, 1976). However, there is much research into convexity properties in computer vision.

This concedes to the ideas put forward by Pasupathy and Connor (2001), who propose as neural network model for the figure-ground organisation which is based on symmetry, parallelism and other spatial arrangement of contours; and also on contour convexity. Within perception research these are all known as effective factors for figure-ground organisation. Spatially separated distant contours must correspond for spatial arrangement of contours to be measurable; these are processed within the model by local detectors embedded in hierarchical architectures of networks, by which image data is pyramidally encoded. The model does succeed in mimicking some features of human perception, as shown by computer simulation.

Additionally, it has been suggested that based on rare but diagnostic regions of acute contour curvature and cell recordings, a sparse object coding scheme in the mid level visual cortex shows peaks at boundaries features, so they lead to shape reconstruction in area V4 of macaque monkeys(Pasupathy & Connor, 2001; Carlson, Rasquinha, Zhang, & Connor, 2011). This is part of the object-related (ventral) pathway in the primate visual cortex (Pasupathy & Connor, 2001; Carlson et al., 2011).

There have been reports of an algorithm which robustly detects salient convex collections of line sections within an image (Jacobs, 1996). This will find all convex sets of line segments in which the fixed proportion of the total length of the lines is greater than the length of the gaps between segments.

Summary of convexity versus concavity studies:

Author (s) and year	**Findings**
(A)Convexity advantage	
Barenhlotz et al (2003)	Change detection easier when convex

	vertexes are introduced.
Bertamini, M (2001)	Faster RT when judging the position of convex region.
Bertamini, M(2008)	No basic change between convexity and concavity.
Bertamini, M & Croucher, C(2003)	Participants are faster when they judging the position of convex vertex.
Haushofer et al(2008)	fMRI response in LOC for convex was higher for different than that for identical pairs.
Hulleman and Olivers (2007)	Reported that deviations from symmetry carried by convexities were easier to detect than deviations carried by concavities
Kanizsa and Gerbino (1976)	Convex regions are chosen as foreground
Bertamini and Lawson (2006)	Significantly increased convex figures.
Bertamini and Lawson (2008)	Convex region affected figure ground organization
Gibson 1994	Convex corners may be easier to compare.
Peterson and Salvagio (2010)	Participants tend to perceived Convex region as a figure ground.
Pao et al 2009	Participants tend to perceived Convex region as a figure ground.
Langer and Bülthoff (2001)	Better performance in convex region rather than concave region.
Sakai and Inui (2002)	The capacity of STVM (short term visual memory) is 4 convex parts.
(B) Concavity advantage	
Bhatt et al(2006)	Easier detect concave vertex.
Cohen et al (2005)	Subjects are more sensitive to changes in concave regions of a shape's contour than to changes in convex regions.
Hulleman et al (2000)	Faster search for concave vertex.
Humphreys and Muller (2000)	A search asymmetry favouring concave over convex targets
Bertamini and Farrant (2005).	The difference between detecting a new convex or concave vertex. Concave vertices and convex vertices both salient.
Feldman and Singh(2005)	Concave region carry a lot of information about part boundaries.
Vandekerckhove et al (2007)	Changes in concave regions of a contour are more easily detected than changes in convex regions.

Table 1.1. This table is illustrated the summary of convexity advantage and concavity advantage studies. The left column is illustrated the Author and the year; whereas, the right column is illustrated the findings of the studies.

Summary of convexity versus concavity studies from the table:

It has been highlighted by recent analyses that both convexity and concavity along a contour may be the foundations for the perception of solid shape and part structure (Hoffman & Richards, 1984; Koenderink, 1984). Thus many studies that have demonstrated effects of concavity and convexity, explain their empirical data in terms how aspects of contours are treated differently by the visual system.

The empirical data fails to explain how advantages for both concavity and convexity are reported for different tasks. In the case of concavity; advantages have been found when using a change detection task (Barenholtz, Cohen, Feldman, & Singh, 2003) and also when using the visual search paradigm (Hulleman, Winkel, & Boselie, 2000; Humphreys & Müller, 2000). Whilst, probe discrimination (Barenholtz & Feldman, 2003), positional discrimination (Bertamini & Farrant, 2005) and detection of symmetry tasks (Hulleman & Olivers, 2007) have all been reported to convey advantages for convexity.

Other studies report that for tasks, such as change detection (Bertamini, 2008) or visual search (Bertamini & Lawson, 2006); there are no differences for concavity and convexity when the perception of part structure is unchanged between the two intervals.

1.6 Objectives of the thesis

The empirical data fails to explain how advantages for both concavity and convexity are reported for different tasks, in the case of concavity; advantages have been found when using a change detection task (Barenholtz et al., 2003) and also when using the visual search paradigm (Hulleman et al., 2000; Humphreys & Müller, 2000). Whilst, probe discrimination (Barenholtz & Feldman, 2003), judging position (Bertamini, 2001) and detection of symmetry tasks (Hulleman & Olivers, 2007) have all been reported to convey advantages for convexity. From this starting point, the primary aim of the present study is to investigate the difference between convex and concave parts in different tasks. In particular we will investigate the corner enhancement effect, visual short term memory performance, perception of symmetry perception, and congruency effect in perception of simple shapes.

Specific objectives:

- To investigate the role of convexity (corner enhancement effect) in perception.
- To investigate the role of convexity in how information is stored in visual short term memory.
- To investigate the role of closure abjectness in visual short- term memory.
- To investigate the role of convexity in perception of symmetry.
- To investigate the role of contour ownership in predicting shape interference.

These objectives are designed to enhance the understanding of the difference between convexity and concavity in perception of shape and to provide a holistic understanding of the difference between convexity and concavity in different tasks (corner enhancement effect, visual short-term memory, symmetry and shape interference).

1.7 Purpose of the research

This thesis utilizes various visual tasks to investigate the difference between convexity and concavity. This can be applied to visual processing; for example in understanding the difference between corner enhancement effect and straight edge effect in object recognition. This information can enhance understanding of the role of convexity and concavity in visual short-term memory and the way in which information is stored in visual short-term memory. Furthermore, this study will reveal the role of convexity in symmetry perception, which may enable understanding of the role of convexity in various types of symmetry, such as reflection and translation. The findings will further the literature on 2-dimensional visual image processing; the human visual system is highly effective at extracting information about object and visual information; particularly contours, because contours transmit a great deal of information about solid shapes. This will improve understanding of shape perception.

1.8 Thesis synopsis

In chapter one, a series of studies on the corner enhancement effect are reviewed. Previous research (Vecera & Farah, 1994; Vecera, Behrmann, & McGoldrick (2000) suggests that object onset has an influence on visual attention. More recently, Cole, Burton and Gellatly (2001, 2007) found that reaction time was shorter for the stimulus located near the corner of the figure. It is possible that corners undertake a more pivotal role than straight edges in visual space, because corners receive more attentional resources than straight edges, as Cole, Gellatly, and Bluton (2001) explains. Additionally, Cole et al. (2001) have shown that the fastest response is for the onset of a probe near a corner. The probe can be the onset of dot, a square or a short horizontal line.

The corner effect has two possible explanations: firstly, corners are more important because they contain more information than straight edges do; secondly, straight edges are an example of an uninformative stimulus and have greater redundancy. This redundancy occurs when the system contains inconsistent information about the stimulus (Cole et al., 2001).

Drawing on a series of experiments, Cole et al. (2001) suggested that the corner effect strongly influences shape representation. It may be helpful for understanding the shape recognition and, as a result, participants will respond better to a stimulus adjacent to the corner rather than a stimulus next to straight edges (Cole et al. 2001). Moreover, Cole, Skarratt and Gellatly (2007) indicated that a stimulus presented in an area next to a corner receives more attention in comparison with the stimulus adjacent to straight edges. For instance, reaction time to detect the target next to the corner was significantly faster than a target next to the straight edges. The present study attempts to decide whether there is a difference between convex and concave corners.

In chapter one, the role of figure ground in the corner enhancement effect is studied. It was found that the corner enhancement effect was present only when the probe is on the surface that owns the corner (Experiment 1a, 1b, 2a, 2b). Therefore, it can be found for both convex and concave vertices. However, no sign of the corner enhancement effect was noticed when the probe was not located on the surface that owns the corner (Experiment 1d, 2c).

Chapter two attempts to determine whether there is a difference between short-term memory for convexities and for concavities (Experiment 3, 4, 5). The capacity of VSTM is limited to four units (Luck & Vogel, 1997; Cowan, 2001; Phillips, 1974). In our studies, the units were segments of a contour. When closed, the contour formed an outline perceived as a single object. The point of interest is whether there is a difference between short-term memory for convexities and for concavities. In this set of studies, a change detection task was employed to examine visual short term memory VSTM. Convexity and concavity in VSTM were compared and it was found that there is no evidence that convexities are special in visual short-term memory, although coding of convexity, as well as concavity, did provide a small advantage over an isolated (and thus ambiguous) contour. This agrees with the known effect of closure on processing of shape.

Chapter three discusses whether the effect found by Hulleman and Olivers (2007) is specific to perception of bilateral symmetry. This recent study reported that deviations from symmetry carried by convexities were easier to detect than deviations carried by concavities (Hulleman & Olivers, 2007). To test whether the convexity advantage was specific to bilateral symmetry, this work was applied to shapes that were repeated rather than reflected (Experiment 6b, 6b). In this set of studies (Experiment 6, 7) we used a detection of symmetry to test if a convexity advantage was specific to bilateral of symmetry. It was concluded that there is a clear convexity advantage for detection of translated objects (6b, 7b). Therefore, no evidence of an advantage for convexity in perception of symmetry was found. Probably, a monitoring strategy focusing on the convexities played a role, in spite of the instructions. Another interesting aspect of the data is the relatively large inter-individual variability. Although in the instructions both concavities and convexities were described to the subjects, and they were told that the deviation from regularity could be in either, some subjects focused more on one region (convexities) and others on another region (concavities). It may be concluded that, for some tasks, performance for convexity was higher than for concavity. This was due to the specific nature of the task, for example, when the task required comparison of features of translated objects, we found a convexity advantage.

In the last chapter, we test that contour ownership determines the presence or absence of interference when the 2D contour information is identical between 2 regions; even for simple shape analysis. We used a task in which figural relationships are irrelevant. Moreover, this task does not involve memory which avoids the possibility of hole shape judgment being affected by memory of the object-with-hole instead of the perceptual response. This chapter is also related to convexity and concavity, but indirectly, as a figure ground change is also a change in convexity coding. The main research question is to explore the role of contour ownership. The prediction is that which surface owns the contour determines the degree of interference between shapes. Furthermore, interference effects were only present when the inside contour and the outside contour belonged to the same surface.

In summary, the principal aim of the present research was to assess the difference between convexity and concavity along a contour in two-dimensional shape (2D), by using different methodological methods. In order to examine the corner enhancement effect, visual short-term memory, symmetry, and shape interference.

CHAPTER 2| The role of figure ground in the corner enhancement effect

This chapter is adapted from Helmy, M.S., & Bertamini, M. (in preparation). The role of figure ground in corner enhancement effect.

Abstract:

Background It has been demonstrated that targets presented adjacent to corners are detected more efficiently than targets presented adjacent to a straight edge. Termed as the *corner enhancement effect*, this phenomenon occurs when a new object whose outline has regions with high and low curvature appears: a probe presented in the spatial region adjacent to a corner (high curvature region) receives an enhancement in processing relative to a stimulus presented in the spatial region adjacent to a straight edge.

Methods A study was designed to test the *corner enhancement effect* for convex and concave corners, which have equal curvature but differ in curvature sign. The probe was a red line presented to the participant near a corner or a straight edge. Shading (Experiment 1) and stereo (Experiment 2) were used to ensure that foreground and background were unambiguously distinct. A discrimination task was utilised, in which the participant was required to judge whether the line was horizontally or vertically orientated.

Results the corner enhancement effect was found for both convex (Experiment 1a and 2a) and concave (Experiment 1b and 2b) vertices. Experiments 1d and 2c tested a situation in which the probe was perceived as a small object not located on any surface, i.e. a floating probe. The corner enhancement effect disappeared when the probe was not perceived as attached to any specific surface.

Discussion the results of this study support the phenomenon of corner enhancement effect occurring when the probe lay on the corner-owning surface. This study further demonstrates that the corner enhancement effect is present only when the probe lies on the corner-owing surface. Therefore, the corner enhancement effect can be found for both convex (Experiment 1a and 2a) and concave vertices (Experiment 1b and 2b); however, it was found to disappear when the probe was not located on the corner-owning surface (Experiment 1d and 2c).

2.1 Introduction

Over the last two decades, a substantial body of work on visual perception and visual attention has developed. The study of visual perception and its role in attention has been explored in many studies. There is an important question raised by the research literature regarding the distribution of attentional resources. There is a possibility that it might be directed to a certain region more than others, or new targets more than old targets.

A significant body of research literature suggests that the onset of a novel object also seems to play an important role in guiding attention to a certain visual regions rather than others (Cole, Kentridge, & Heywood, 2004, Gellatley & Cole, 2000; Gellatley, Cole & Blurton, 1999; Yantis, 1993). This spatial attention processing facilitates information processing about the target of focus, and simultaneously restrains the processing of information about unattended targets (Cole, Gellatley, & Blurton, 2001). For instance, Cole et al. (2001) proposed that a stimulus has a processing advantage when presented in a spatial region close to the corner of a new object relative to a stimulus presented in a spatial region close to the straight edges, Cole et al. discovered that reaction time (RT) for detection of a target positioned next to a corner is faster relative to a target positioned next to a straight edge. This phenomenon is called the corner enhancement effect (cited hereafter as “the corner enhancement effect”).

Cole et al. (2001) also investigated to what extent the corner effect might increase understanding of the object/shape perception process. As stated by Hebb (1949), lines are considered to hold a particular importance for the perception of shape, and have additionally been proposed to constitute perceptive elements in a hierarchy of feature primitives. Such primitives are regarded as the building blocks on which more sophisticated shape perception is based. It is also accepted that corners play a similarly significant role in shape perception. So in the visual field, a stimulus presented in a region of space adjacent to a *corner* receives enhanced processing *relative to* a stimulus presented adjacent to a *straight edge*: response times for detection are faster near a corner.

There is good evidence to support the Gestalt principle that contours only belong to figures. Rubin (1915-1958) was one of the first researchers to explore the perceptual phenomenon of figure-ground organization: in his famous example the vase-shape can also be seen as the edges of two faces. The face profile can be a figure on a shapeless ground, or, on the other hand, the vase region can equally be perceived as a figure (the vase), while the background region appears shapeless (Stevens & Brookes, 1988; Peterson & Kim, 2001; Baylis & Cale, 2001; Vecera et al., 2004; Burge, Peterson & Palmer, 2005; Vecera & Palmer, 2006; Pinna, Werner, & Spillmann, 2003; Peterson & Salvagio, 2010). In studies where participants have to remember a shape, they are able to successfully recall shapes that are perceived as figure, but not those perceived as background (Kanizsa & Gerbino, 1976; Baylis & Cale, 2001).

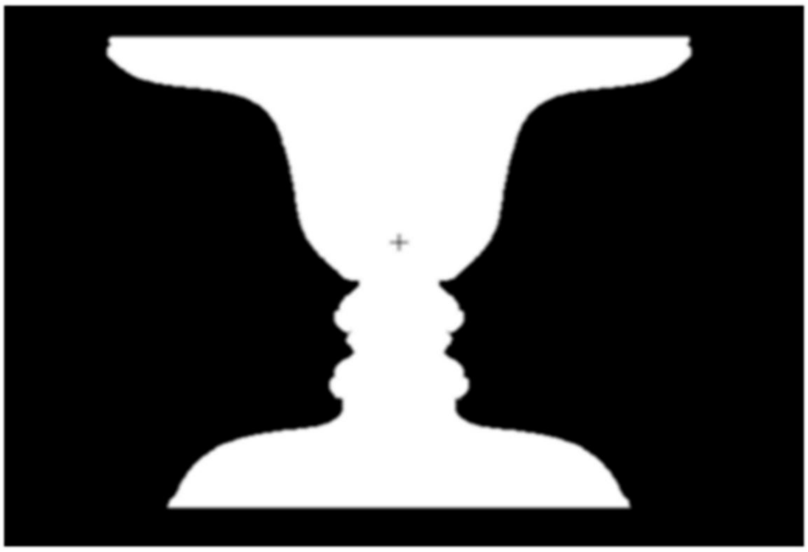


Figure 2.1 The Rubin vase–faces display illustrated the phenomenon of figure-ground organization. Observers switch between seeing the black region and the white regions as the foreground.

There are two main conclusions that follow from this figure-ground perception phenomenon:

- The figural region appears to have shape, whereas the ground appears to have no shape; and
- The figure is perceived as being “closer", with the ground region appearing to continue behind the figure (Stevens & Brookes, 1988; Peterson, & Kim, 2001; Baylis & Cale, 2001; Vecera et al., 2004; Burge, Peterson, & Palmer, 2005; Vecera & Palmer, 2006; Pinna, Werner, & Spillmann, 2003; Peterson & Salvagio, 2010).

Gestalt psychologists first pioneered the idea that an area of the visual field is more conveniently and readily dissolved into components as figure rather than ground. They recognized the role of figure–ground in human perception. Figure-ground also plays a crucial role in the processing of contour curvature because a contour’s sign of curvature is determined by figure-ground assignment (positive for convex contour and negative for concave contour).

Gestalt psychologists distinguished between figure and ground: the figure has a definite shape, whereas the ground is perceived as shapeless. Gestalt psychologists have demonstrated that the figure tends to be more organized, structured and to have a more “thing-like” character; this means that a region that is more fluent and detailed tends to be seen as the figure (Koffka, 1935; Rubin, 1915, 1958; Peterson & Kim, 2001; Peterson & Skow, 2008; Palmer & Ghose, 2008). For example, Driver and Baylis (1995) investigated which side of the contour had a decisive importance in shape perception. They depended on Gestalt cues in their experiments; asking the participants to remember the curved-edged shape-stimuli assigned as either figure or ground. The results indicated that performance was faster and more accurate when the shape used in the experiment was viewed as a figure rather than as background. This demonstrates that convexity plays an important role both in making changes to shapes, and as a component part of human perception (Driver & Baylis, 1995).

Numerous researchers have investigated the properties of figure–ground perception, and established a recognised set of perceptual cues known as “Gestalt configural cues”. These cues help to determine which regions will appear as figures, rather than as ground:

(1) Rubin (1915/1958) demonstrated that smaller regions and enclosed regions are likely to be perceived as a figure.

(2) Bahnsen (1928) suggested that symmetrical regions are more likely to be seen as figure.

(3) Kanizsa and Gerbino (1976); Hoffman and Singh, (1997) found that convex regions are more likely to be perceived as figures than adjacent, concave regions. Regions that are open and larger in area tend to be perceived as background.

(4) Vecera, Vogel, and Woodman (2002) demonstrated that regions in the lower portion of a stimulus array appear more figure-like than regions in the upper portion of the display.

(5) Klymenko and Weisstein (1986) concluded that regions with the highest spatial frequency are perceived as figures.

(6) Peterson and Gibson (1994) showed that regions depicting familiar objects are more likely to be perceived as figures.

(7) Hulleman and Humphreys (2004) concluded that regions with a wide base are likely to be perceived as a figure (Kimchi & Peterson, 2008; Peterson & Lampignano, 2003; Peterson & Skow, 2008).

Participants are more easily able to recognize targets perceived as figure than those perceived as ground. In memory, people cannot easily recall a shape which belongs to a background, but they are able to recall more easily a figure-related shape (Nelson & Palmer, 2007). These results appear to be consistent with the research of Lazareva, Castro, Vecera, and Wasserman (2006) who concluded that pigeons are able to recognise targets more easily and more quickly when they are figure rather than ground. However, their paper does not draw conclusions regarding whether that advantage is due to attention to the regions that are perceived as a figure or not(Nelson & Palmer, 2007).

Mazza, Turatto, and Umita (2005) demonstrated that by using the change blindness paradigm participants are able to identify target shapes both faster and more accurately when they perceive a shape as figure rather than as background. More importantly, participants were, in 90% of all trials, more easily and accurately able to discriminate changes in shapes perceived as figure than those perceived as ground.

Klymenko and Weisstein (1986) found that when a target contained high spatial regularity components it was detected better in figural regions, but when it contained low spatial regularity it was conversely detected better in ground regions.

There is substantial research supporting the important role of the figure-ground relationship in visual perception, as it facilitates the creation of regions to which features (such as shape descriptions) are then assigned. There is, however, some disagreement as to how much dependency shape analysis has on figure-ground. The purest form of a figure-ground organization comes from the perceived reversal in figure-ground of a closed region. The perception resulting from this reversal is either that of an object or a hole.

For example, Vecera, Vogel, and Woodman (2002) concluded that when two regions are respectively located above and below a shared contour, the lower of the two regions tends to be perceived as a figure. This is because the lower region tends to be closer to the participant in comparison with the upper region. Their conclusions would suggest that this "lower region principle" should also be considered a significant factor in figure-ground perception (Vecera & Palmer, 2006).

Driver, Baylis, and Rafal (1992) studied a patient with right-hemisphere brain damage and suffering from severe left-hemisphere neglect. Their study involved presenting the participant with two separate sets of stimuli; the first display was smaller and brighter and the second display was larger and dimmer. They asked the participant to decide whether the dividing contour matched a probe line. The results indicated that the patient's performance was better when the stimulus display was smaller and brighter, in turn suggesting that the smaller and brighter section is more salient than the second section (larger and dimmer). The small, bright display was therefore more likely to be perceived as a figure (Driver et al., 1992).

Another line of evidence comes from a series of experiments conducted by Kimchi and Peterson (2008). They asked study participants to detect the convexity and concavity. Their study illustrated that participants' performance was better when the figure and the background were similar: responses to the same targets would be more rapid when the background stayed the same than when it changed. Conversely, responses to differing targets would be more accurate when the background changed than when it was the same. These findings indicate that convexity is a powerful cue for figural assignment, and the relationship between figure–ground perception and attention is complicated (Kimchi & Peterson, 2008).

In summary, based on this shared understanding of the relationship between shape perception and figure-ground perception, we can conclude that it is impossible to disentangle these two elements of visual perception. Figure-ground perception occurs when adjacent regions share an edge: only one of the two regions is perceived as a figure, while the other region appears as ground. In other words, a figure is attributed with shape and appears to occlude the background, whereas the ground appears to be essentially shapeless near the borders it shares with a figure (Peterson & Gibson, 1994). There is general agreement on the idea that that figure–ground organization is important and that shape perception is inextricably linked with figure-ground processing.

Research literature in his area has controversially suggested a possible difference in change detection performance between concavity and convexity. A number of perceptual tasks are particularly sensitive to concavity or convexity coding; it is presumed that this is a result of this type of coding having an important role in part parsing (Bertamini, 2001; Hulleman et al., 2000). In terms of the question of differences in detection, Barenholtz et al. (2003), and more specifically Cohen et al. (2005), have put forward the argument that detection performance for changes in concavities is higher relative to changes in changes in convexities. Conversely, it has been argued that when care is taken to match both concave and convex conditions, the difference to sensitivity disappears (Bertamini, 2008).

This literature suggests an important question regarding whether a target located in a region of space adjacent to a corner of a new object stimulates enhanced processing, when compared with targets presented next to a straight edge. More specifically, this question addresses the role of figure-ground in the corner enhancement effect. A series of experiments were conducted in the course of this study to test this hypothesis.

In the original study, Cole et al. (2007) asked observers to detect a probe onset that could be located either near the corner or along the straight edge of an object. Typical RTs were quite fast, which could be due to a lack of task difficulty. In order for this to be remedied, the work was extended in the present study, to investigate differences in the corner effect between convex and concave corners for a task that involves a discrimination task (Cole et al. also had at least one exp with a discrimination task). Therefore this study did not use simple RT to onset; but instead used a discrimination task (horizontal or vertical). As discussed previously, principles of figure-ground may have implications in terms of contour perception. Therefore, in terms of the role concavity and convexity, this study required that the foreground and background be unambiguously distinct from one another. In order to address this, monocular shading was used to create a sense of surface layout (Bulthoff & Mallot, 1988; Vuong, Domini, & Caudek, 2006; Harris & Wilcox, 2009).

A second manipulation extended the findings to figure-ground organization specified by binocular disparity alone, using random dot stereograms (only random dot stereograms isolate disparity as the sole source of depth information). It was hypothesised that the stimuli position relative to a corner will be afforded more attentional resources, and that relative differences will be seen between concave and convex corners (illustrated by decreased reaction times). In order to investigate this, a series of experiments was conducted to test this hypothesis. Before describing these, it will be helpful to present examples of the stimulus that Cole et al. (2007) used in their experiments.

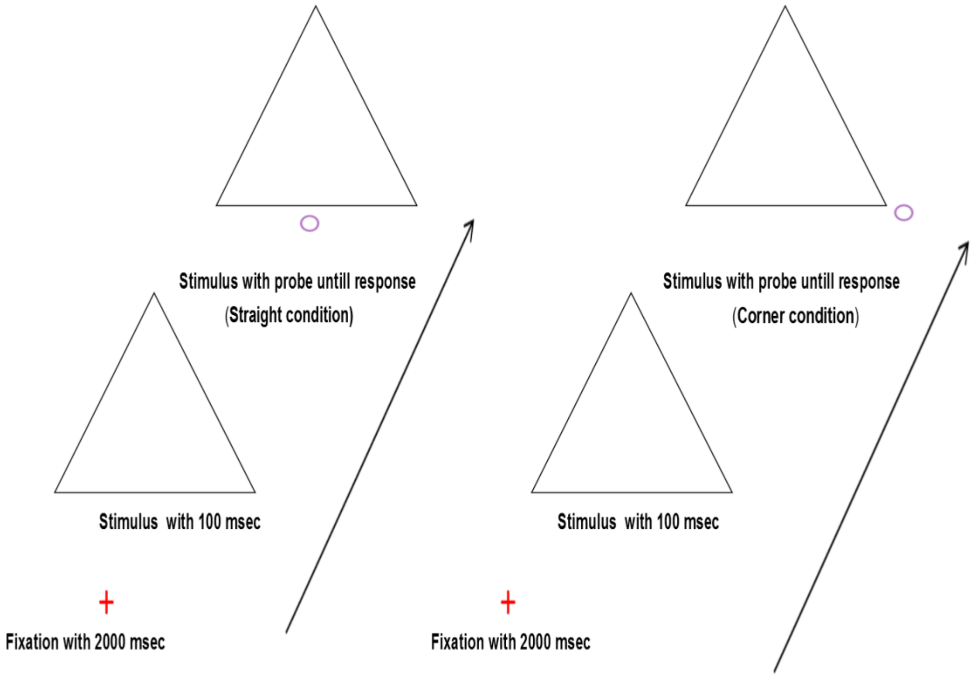


Figure 2.2 illustrates some examples of the stimuli used by Cole et. al (2007). The structure of a single trial; after a fixation screen, the stimulus with 100 msec and after that the stimulus with probe until response. For the stimulus the probe could either be on the corner or on the straight edge. Rather than for the stimulus on the left hand the target becomes a straight edge. If, by contrast, this same target is presented with the right hand triangle, the target now becomes a corner target. Before describing the details of the experiments undertaken in the course of this study, it may be helpful to list all of the experiments undertaken to investigate corner enhancement effect (Table 2.1).

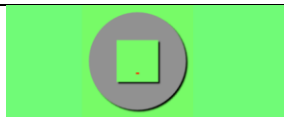
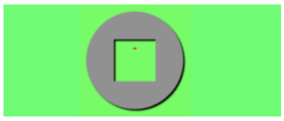
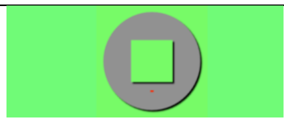
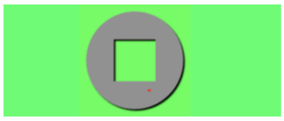
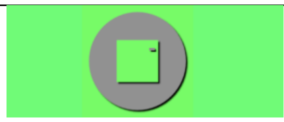
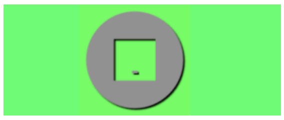
Experiment title	Experiment aim	Stimuli
(1a-2a) Inside object.	To test the enhancement corner using the same methodology of Cole et al. (2001) (horizontal or vertical discriminate task).	 
(1b-2b) Outside object.	As Experiment 1 with the exception that the probe was located on a different surface compared to Experiment 1.	 
(1d-2c)Experiment floating.	This Experiment used a new situation: the object was not located on top of the surface, but rather on the same depth plane to test whether corner enhancement effect still exists when objects do not belong to the same surface.	 

Table 2.1. This table is illustrates the corner enhancement effect experiments; the inside object (Ex 1a, 2a), Outside object (Exp1b, 2b), and Floating Experiment (Exp 1d, 2c).

(Experiment 1)

General method

The purpose of Experiment 1 is to investigate differences in the corner effect between convex and concave corners for a task that involves a discrimination task (Cole et al., 2001) also had at least one exp with a discrimination task).

Participants

Participants for this study consisted of 44 people (ten participants for each condition of the experiment, except 14 participants for Experiment 1c). An opportunity sampling methodology was adopted drawing participants from the student population of the University of Liverpool either voluntarily or in return for course credit. Ages ranged from 18 to 21 (*M* = 20 years). All participants were right handed and were naive with respect to the experimental hypothesis and all signed the consent form.

Design

The independent factors were shape (figure or ground), layout (whether the figure was on the right or on the left), and position (whether the vertex was next to a corner or a straight edge). The dependent factor was reaction time relative to the position of the probe.

Apparatus

The stimuli were presented on a monitor (resolution 1024X 768 at 85 Hz) controlled by an Apple Macintosh computer. The actual position of the stimulus was randomly varied in each trail around the centre of the monitor to discourage observers from using positional cues. This promotes a more holistic view of the display and avoids a strategy of focusing on position with respect, to say, the frame of the monitor convex corner and the concave corner.

In terms of the actual presentation of the stimuli, a background fixation point would be used to hold participants attention to the centre of the screen. This comprised of a light green rectangle (0.8 deg wide by 0.4 deg tall) with a cross in the centre indicating where participant vision must be focused. The stimulus was a grey two-dimensional circle (0.66 deg circumference), the inner edges of which were defined by a two-dimensional light green square (0.28 deg each side). The probe was a red rectangle (0.40 deg wide by 0.20 deg tall)**,** which would appear next to either a corner or a straight edge of the light green square, and had either a horizontal or vertical orientation. A UK English language keyboard was used to collect participant responses.

Procedure

Each participant sat in a dimly illuminated room at a distance of approximately

57 deg from the monitor. The participants were given instructions and shown examples of the stimuli before the experiment started. The participants were asked to discriminate the orientation of the probe (horizontal or vertical); it was stressed that participants should attempt to respond as quickly as possible to the position of the probe. The probe remained on screen until a response was made. Once the session started, 20 trials formed a practice phase, and after this a message appeared asking the participant to start the experiment by pressing the space bar. In the monocular shading experiment condition, each participant performed 192 trials. The trials were presented in rapid succession, but after 64 trials a block ended and the observer was allowed time to rest. The start of the subsequent blocks was self-paced, and each subsequent block consisted of 96 trials. The computer recorded response time and controlled the presentation of stimuli. Participants were asked to respond as quickly as possible to the position of the probe, using the key ‘’/” if it was horizontal and the key ‘’z” if it was vertical.

The structure of each trial followed the same progression. Background fixation was presented to the participant for 2000 milliseconds. After 100 milliseconds the stimulus would appear with the probe located somewhere along the edge of the stimuli. This would remain upon the screen until a response was made. Once a response was made the background fixation would reappear and the process would begin again until the task reached its conclusion (see Figure 2.3).

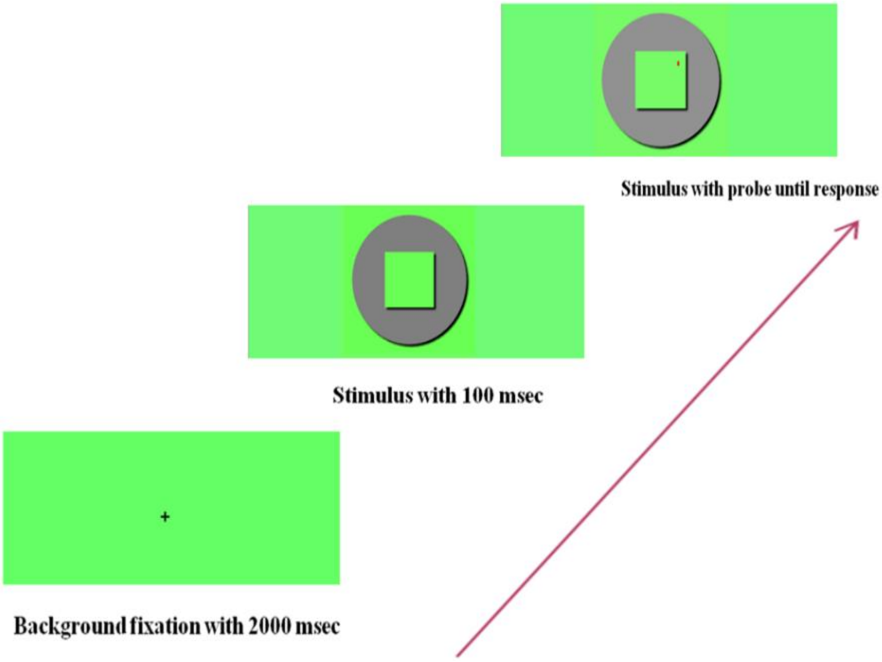


Figure 2.3 The structure of a single trial; after a fixation screen with 2000 msec, the stimulus presented with 100 msec, and the stimulus presented either on the right or on the left of the stimulus with probe until response.

2.2 Experiment 1a

Method

Experiment 1a used stimuli in which there were no average luminance differences between regions. This experiment was designed to test the corner enhancement effect using the same methodology employed by Cole et al. (2001). This experiment used a discrimination task (horizontal or vertical) rather than simple RT to onset (see Figure 2.4 and 2.5). In this condition the green figure ground has a corner in the condition in which there is an object in it.

2.2.1 Participants

Ten participants were drawn from the student population of the University of Liverpool either voluntarily or in return for course credit. Ages ranged from 18 to 21 (*M* = 20 years), six female and four male participants were involved. They had normal vision, were all right handed and were naive with respect to the experimental hypothesis.

2.2.2 Stimuli

The priming figure was a polygon, and the probe took the form of a small line which appeared next to either a corner or a straight edge (horizontal or vertical position). Participants were asked to respond as quickly as possible to the position of the probe, using the key ‘’/’’ if it was horizontal and the key ‘’z’’ if it was vertical. The time presentation of the probe stayed on the screen until the participant made their response. The factors were shape (corner versus concave and straight edges), layout (where is the figure was on the right or on the left), and position (whether the vertex was next to a corner or a straight edge). They were factorially combined in a within-subjects design. The experiment tested the hypothesis that there should be a recordable difference in response between different types of corners. Examples of the stimuli used are illustrated in Figure (2.4 and 2.5). The stimuli were presented on a monitor (resolution 1024X 768 at 85 Hz) controlled by an Apple Macintosh computer. The actual position of the stimulus was randomly varied in each trial around the centre of the monitor to discourage observers from using positional cues. This promoted a more holistic view of the display and avoided a strategy of focusing on position with respect to, for example, the frame of the monitor’s convex corner (on the left) and concave corner (on the right).

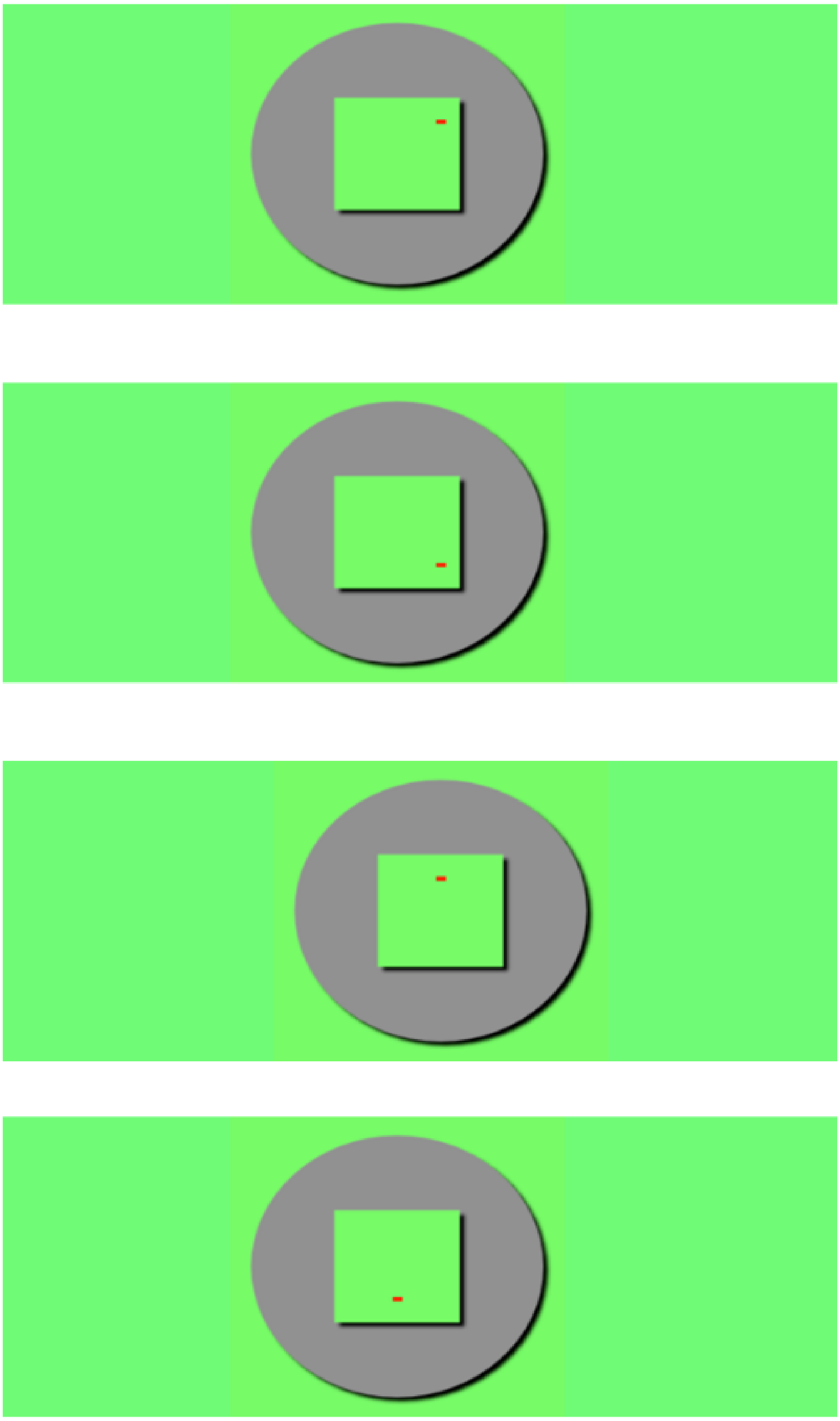


Figure 2.4 Examples of the stimuli used in Experiment 1a. In this condition the probe is inside the square region, and the corner is convex because the region is perceived as foreground.

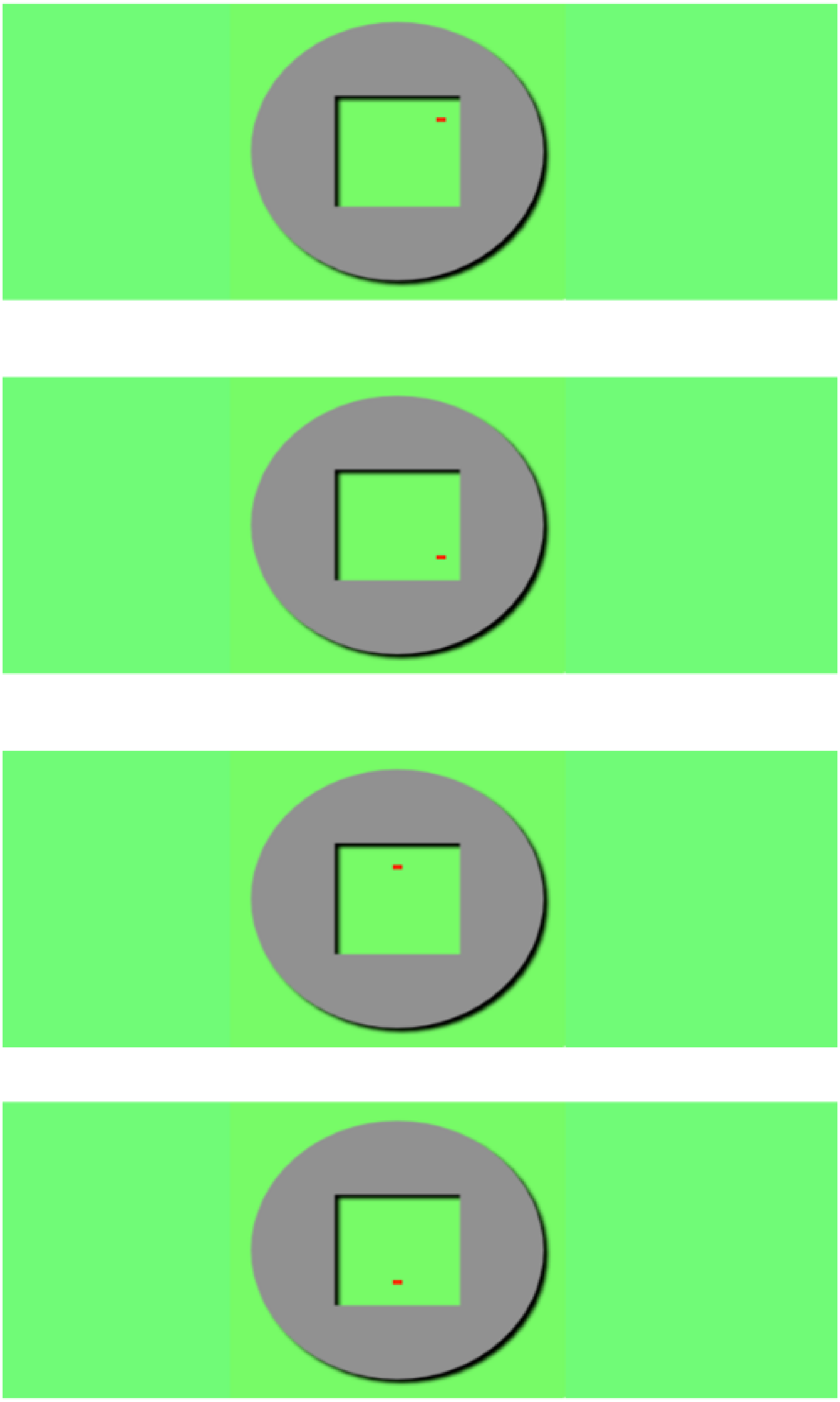


Figure 2.5 Examples of the stimuli used in Experiment 1a. In this condition the probe is inside the square region, and the corner is perceived as concave (hole).

2.2.3 Results

Response times and average error rate are shown in Figure 2.6. Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.1%, hole straight is 0.1 %, object corner is 0.7 % and object straight is 0.0%.

A mixed ANOVA was performed to compare the effects of object (hole or object) and corner (corner or straight edge) on reaction times for a discrimination task, in a condition where the probe sat on the surface that “owned” the corner. A significant effect was found for corner ($F(1,9)=41.31$, $p<0.001$, partial $\eta^2=0.50$) and a significant interaction was found for “objectness” and corners ($F(1,9)=51.04$, $p<0.001$, partial $\eta^2=0.68$).

To test the corner enhancement effect separately for the hole condition and object condition respectively, a set of t-test were performed, responses were faster in the corner compared to straight position for the objects ($t(9)=7.54$, $p=0.001$); and for holes there was no difference ($t(9)=1.03$, $p=0.328$, n.s).

These results therefore demonstrate that targets located in a region of space adjacent to a corner of a new object accrued enhanced processing (in a convex region), as compared with targets presented next to a straight edge. Furthermore, probes located on top of a surface have been demonstrated to have a corner advantage. However, no effect was found for probes located on a square hole within circular surfaces.

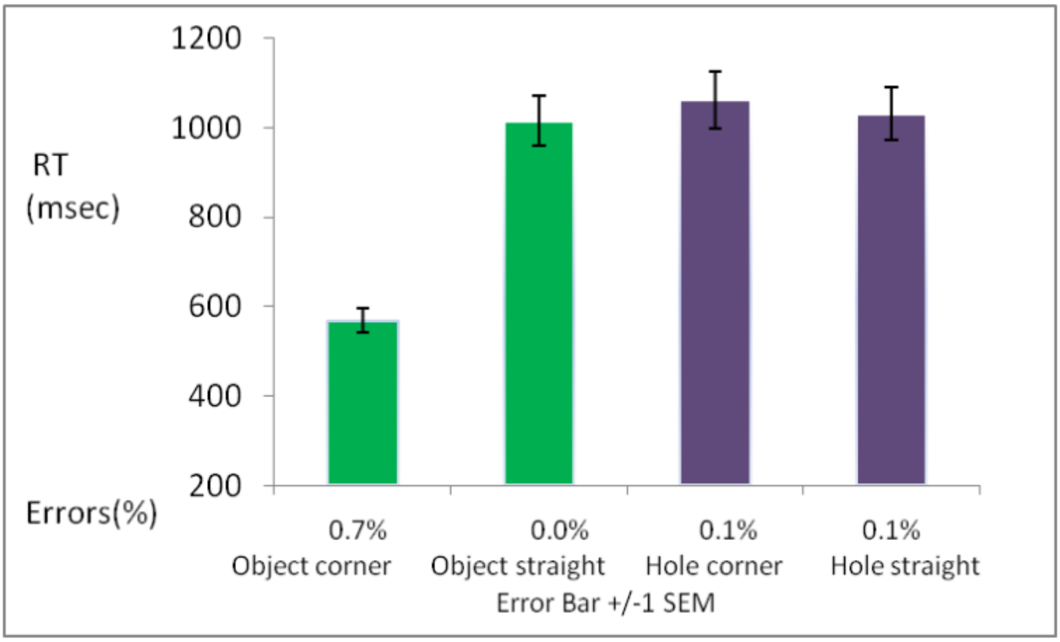


Figure 2.6 Results from Experiment 1a. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

2.2.4 Discussion

These results replicated those of Cole et al. (2001), finding that targets located in a region of space adjacent to a corner of a new object stimulated enhanced processing, as compared with targets presented next to a straight edge. The present findings extend the results of Cole et al. by showing that when a target is set on a square surface overlaying a circular surface (and is hence perceived as a figure/object), then this object is perceived as owning a corner. Conversely, when the target is set on a square hole lying within a circular surface (and is hence perceived as a hole), then this hole is perceived as not owning a corner (convex corner).

The results of the present study differ from those of Cole et al. (2001) in one aspect: in the present study the corner enhancement effect advantage was found to appear inside the object, which was not the case in Cole study. In the experiment undertaken in the course of the present study the object was found to have a corner enhancement effect because of the target's setting on the green surface, removing it from the object. Conversely, when the target appeared on the background of the green surface, the target was perceived as having no corners. Therefore no difference was perceived between targets located on a corner or on a straight edge, because neither owned a corner.

2.3 Experiment 1b

Method

Experiment 1b followed the same procedure. The stimuli were similar, but were presented on a different surface; in this case, the targets were set on the gray background (which is round and has no corners) whereas in the previous experiment the target's setting was inside the object, perceived as having corners (see Figure 2.7 and 2.8). In this condition the gray background has a corner in the condition in which there is a hole in it. The probe was aligned in either a vertical or horizontal position. This experiment was designed to test the hypothesis that when a target is not set on a square surface overlaying a circular surface (and is hence perceived as a figure/object), then this object is perceived as not owning a corner. Conversely, when the target is set on a circular surface (and is hence perceived as a hole), then this hole is perceived as owning a corner (concave corner).

2.3.1 Participants

Ten students at the University of Liverpool participated. Four were female. Ages ranged from 18 to 21 (M = 20 years), six female and four male participants were involved). They had normal vision, were all right handed and were naive with respect to the experimental hypothesis.

2.3.2 Stimuli

Examples of the stimuli are illustrated in Figure 2.7 and 2.8.

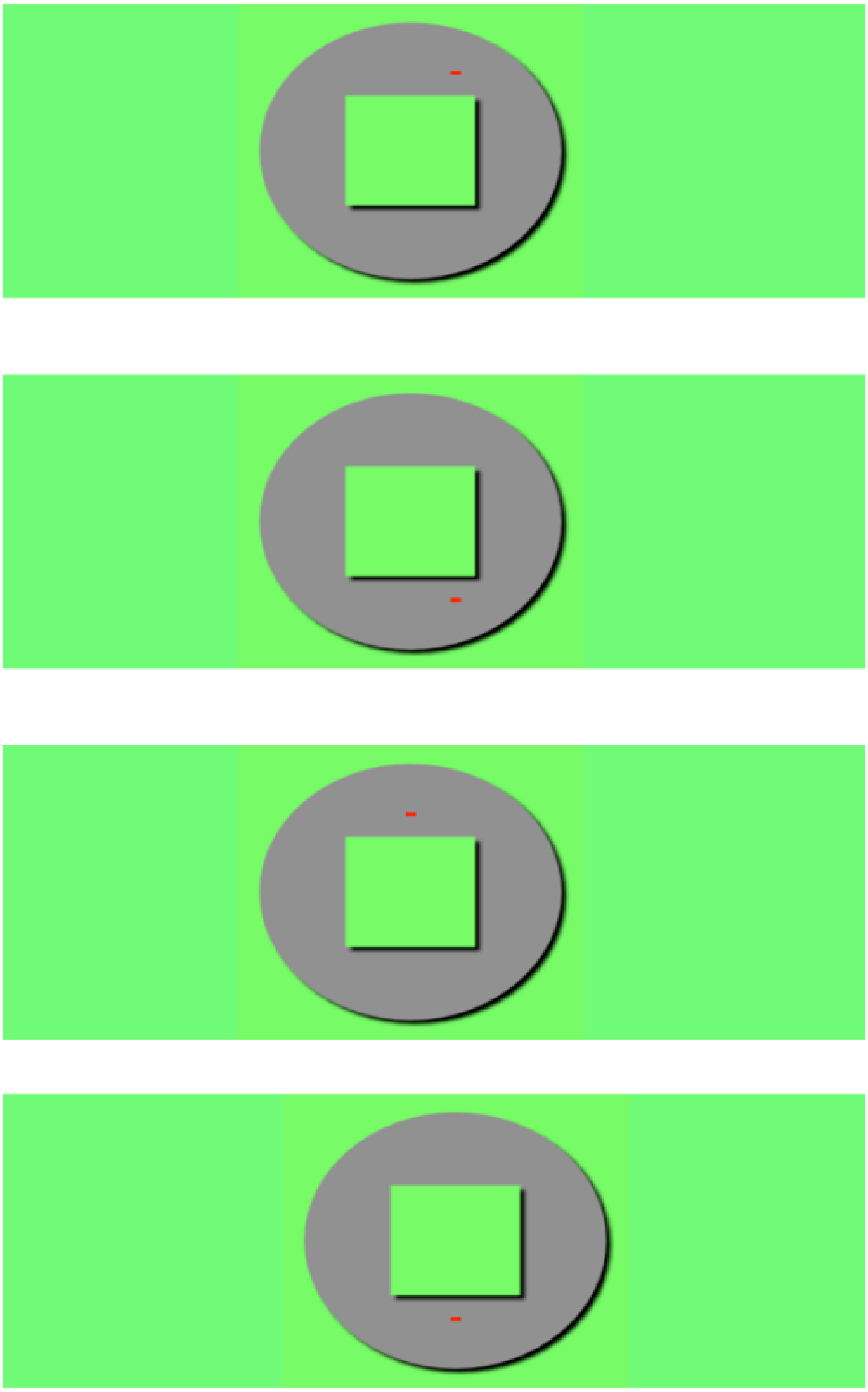


Figure 2.7. Examples of the stimuli used in Experiment 1b. In this condition the probe is outside the square region, and the corner is convex (the square is foreground).

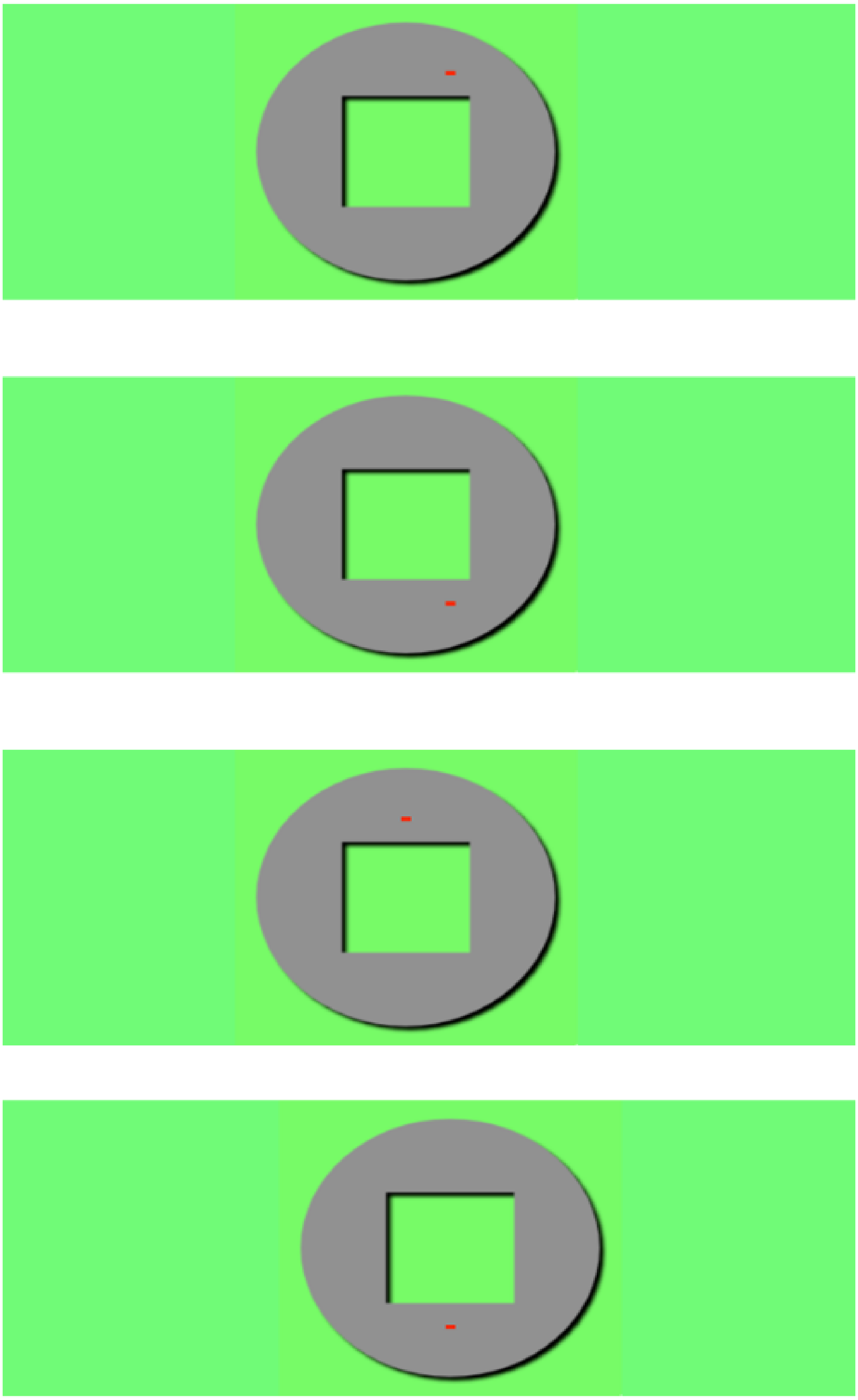


Figure 2.8. Examples of the stimuli used in Experiment 1b. In this condition the probe is outside the square region, and the corner is concave (the square is a hole).

2.3.3 Results

Experiment 1b: In this experiment the location of the probe was changed, presented on the surface that did not own the corner. More specifically, it was located along the outer edge of the square region as shown in Figure 2.7 and 2.8. In this condition, the corners had convex vertices in the object condition and concave vertices in the hole condition. Response times and average error rate are shown in Figure 2.9. Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.9% , hole straight is 0.2 %, object corner is 0.3 % and object straight is 0.1%.

A mixed ANOVA was performed to compare the effects of object (hole or object) and corner (corner or straight edge) on reaction times for a discrimination task, in a condition where the probe sat on the surface that did not own the corner. A significant effect was found for objectness ($F(1,9) = 9.32$, $p<0.014$, partial $\eta^2=0.50$). Corners were also found to be significant ($F(1,9) = 36.17$, $p< 0.001$, partial $\eta^2=0.80$) and another significant interaction was found for “objectness” and corners ($F(1,9) = 19.18$, $p<0.002$, partial $\eta^2= 0.68$). To test the corner enhancement effect separately for the hole condition and object condition respectively, a set of t-test were performed, responses were faster in the corner compared to straight position for the holes(t (9) =-3.70, p = 0.005); and for objects there was no difference (t (9) =-1.97, p= 0.070, n.s).

The results of Experiment 1b demonstrate that targets located in a region of space adjacent to a corner received an enhancement in terms of processing, when compared with targets presented next to a straight edge. It has also been demonstrated that in the holes condition the target probe is perceived as belonging to the surface that owns the corner, and in this cases the corner processing is concave vertices.

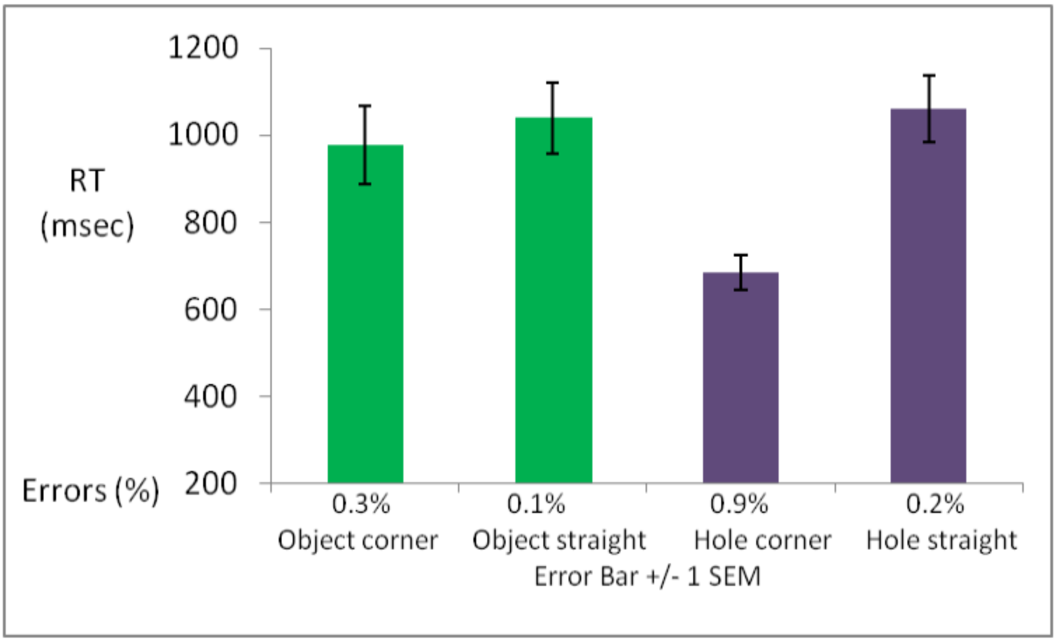


Figure 2.9. Results from Experiment 1b. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

2.3.4 Discussion

The results of Experiment 1b therefore show that the targets located in a region of space adjacent to a corner of a new object stimulated enhanced processing, as compared with targets presented next to a straight edge. These data clearly show that objects' corners stimulated an attentional advantage, relative to the baseline probes positioned on the straight edges. In this experiment in the hole condition there was a corner enhancement effect because the target was set on the background with the hole. Conversely, when the probe appeared on top of the surface (figure), the target was perceived to have no corners; therefore no difference was perceived between targets located on a corner or on a straight edge, because neither owned a corner.

2.4. Experiment 1c

Method

In Experiment 1c we tested the hypothesis that the corner enhancement effect present when the probe lay on the surface that owns the corner. We mixed the inside and outside conditions (unlike Experiment 1a and 1b where this was a between-subjects variable) to ensure validity.

2.4.1 Participants

Fourteen students at the University of Liverpool participated. Four were female. Ages ranged from 18 to 22 (*M* = 20 years).

2.4.2 Stimuli, Design and Procedure

The same procedure as Experiments 1a and 1b.

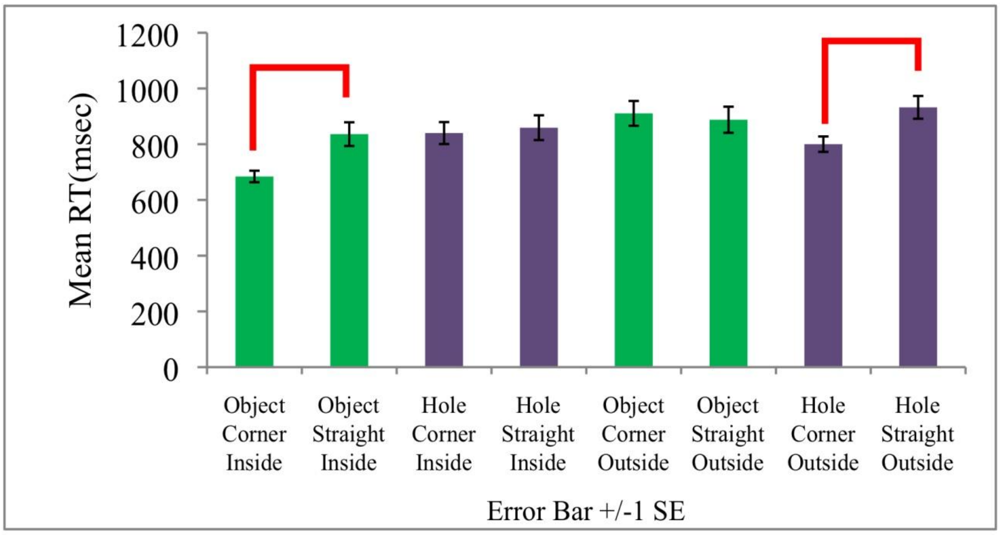


Figure 2.10. Results from Experiment 1c. For each condition the bars show the mean response time for corner and straight edge for both holes and objects.

2.4.3 Results

We performed a repeated-measures ANOVA with objectness (object and hole), corner (corner and straight edge), and location (inside and outside) as within-subjects factors. There was a significant effect of objectness (F(1,13)=82.91, p =0.001, partial

η^2= 86.4, and an interaction between objectness corner and location (inside and outside)($F(1,13)$=9,42, p =0.002, partial η^2= 0.42). To test the corner effect for the hole condition and for the object condition separately, a set of t-test were performed. For the inside condition, responses were faster in the corner compared to straight position for the objects (t (13) = 4.46, p = 0.001). For the outside condition, responses were faster in the corner compared to the straight position for the holes (t (13) =2.91, p = 0.012). These results replicated the results of Experiment 1a and 1b. We conclude that corner enhancement effect was present only when the probe is on the surface that owns the corner.

2.5. Experiment 1d

Method

In Experiments 1a and 1b the corner enhancement effect was present only when the probe was positioned on the surface perceived as owning the corner. In Experiment 1d, we test the hypothesis that corner effects are absent when the probe is not located on the background surface that owned the surface. This was done by creating a probe with monocular shading, which would define it as being different in depth compared to the surface the probe lay on. Perceptually, the probe no longer belonged to any specific surface and would be viewed as floating (see Figure 2.11 and 2.12).

2.5.1 Participants

Ten students at the University of Liverpool participated. Ages ranged from 18 to 22 (M = 20 years). Six participants were female and four were male.

2. 5.2 Stimuli

Examples of the stimuli used are illustrated in Figure 2.11 and 2.12.

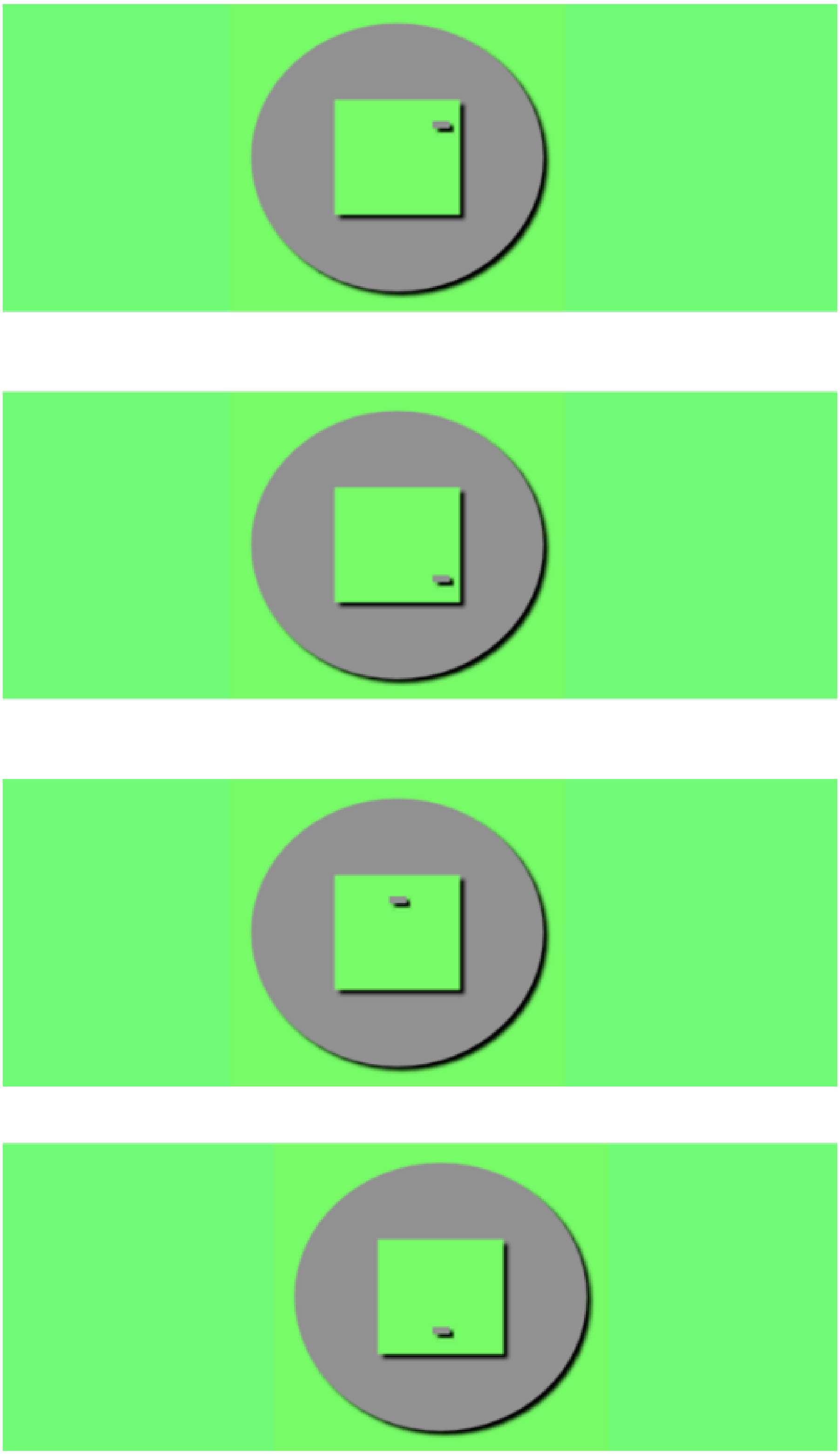


Figure 2.11. The stimuli used in Experiment 1d; probes with floating (object) condition.

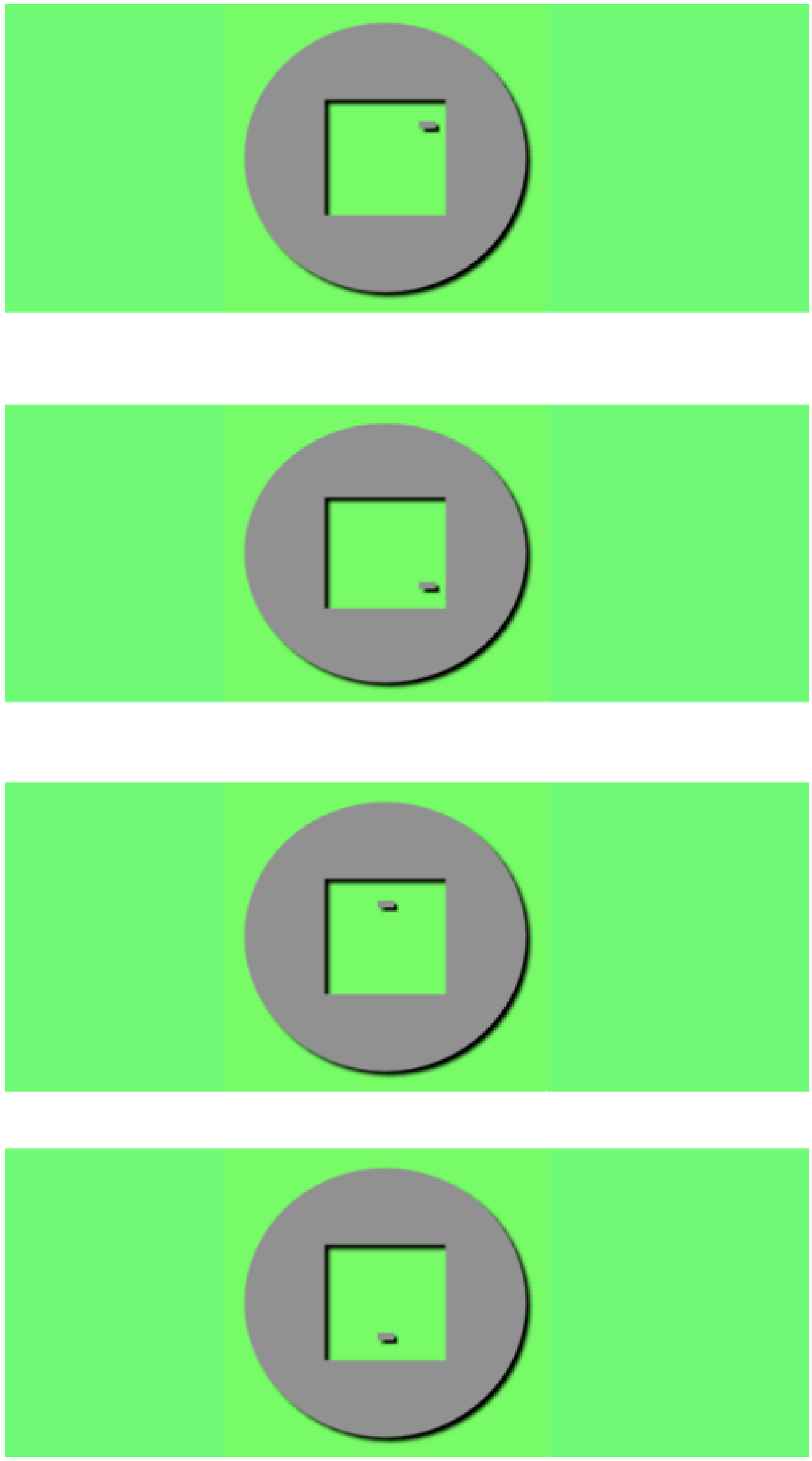


Figure 2.12. The stimuli used in Experiment 1d; probes with floating (hole) condition.

2.5.3 Results

Response times and average error rates are shown in Figure 2.13. Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.1% , hole straight is 0.2 %, object corner is 0.2% and object straight is 0.2%.

A mixed ANOVA was performed to compare the effects of object (hole or object) and corner (corner or straight edge) on reaction times for a discrimination task, in a condition where the probe was perceived as floating above the surface owning the corner. There was no significant effect for objectness (F (1,9) =1.28, p >0.286. partial η^2 =0.125 and there is no interaction between objectness and corner (F(1,9) =0.280, p >0.61, partial η^2=0.030). To test the corner enhancement effect separately for the hole condition and object condition respectively, a set of t-test were performed. For the holes condition, there was no difference in the corner compared to the straight position (t (9) =1.77, p= 0.110 n.s); and for objects there was no difference (t (9) =0.96, p= 0.361 n.s). The lack of interference for all conditions leads to the conclusion that corner enhancement effect cannot be processed independently from the surface belonging to the same depth.

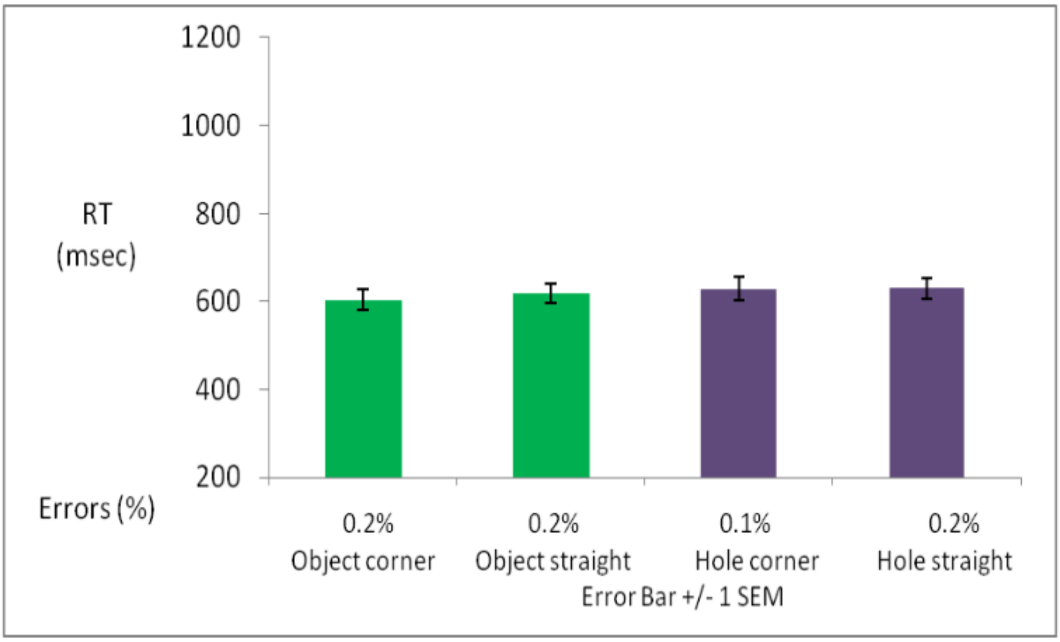


Figure 2.13. Results from Experiment 1d. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

In Experiment 1(a, b) we found that targets located in a region of space adjacent to a corner received an enhancement in terms of processing, when compared with targets presented next to a straight edge. It has also been demonstrated that the corner processing shown when the target probe is perceived as belonging to the surface that owns the corner. In Experiment 2 we attempted to replicate the findings of Experiment 1 by using different depth cues to aid us enhance our understanding of perception of shape in general, and more specifically, the corner enhancement effect in 2D and 3D. For example, Koenderink (1984) analyzed the situation where the 2D contour may be the projection of a 3D object (Koenderink, 1984).

(Experiment 2)

General method

In Experiment 2 we tested the hypothesis that the corner enhancement effect present when the probe lay on the surface that owns the corner. It is not manipulated by monocular shading as Experiment 1 but it is manipulated by binocular disparity alone, using random dot stereograms (only random dot stereograms isolate disparity as the sole source of depth information).

Participants

Thirty participants took part in this study (ten participants for each condition). An opportunity sampling methodology was adopted, drawing participants from the student population of the University of Liverpool either voluntarily or in return for course credit. Ages ranged from 18 to 21 (M = 20 years). All participants were naive with respect to the experimental hypothesis. Those who were exposed to the stereogram condition were all able to see proficiently in stereo as shown having demonstrated adequate scores on the TNO test for stereoscopic vision.

Design & stimuli

The same design and the same stimuli as in Experiment 1.

Procedure

Each observer sat in a dimly illuminated room at a distance of approximately 57 deg from the monitor. The observers were given instructions and shown examples of the stimuli before the experiment started. The participants were asked to discriminate the orientation of the probe (horizontal or vertical); it was stressed that participants should attempt to respond as quickly as possible to the position of the probe. The probe remained on screen until a response was made. Once the session started, 20 trials formed a practice phase, and after this a message appeared asking the observer to start the experiment by pressing the space bar. Each participant was required to complete the TNO test for stereoscopic vision prior to the experiment, and their scores were recorded. Each participant performed 288 trials. The trials were presented in rapid succession, each block consisting of 96 trials. The start of the subsequent blocks was self-paced.

The computer both recorded response time and controlled the presentation of stimuli. Participants were asked to respond as quickly as possible to the position of the probe, using the key ‘’/” if it was horizontal and the key ‘’z” if it was vertical.

The structure of each trial followed the same progression: background fixation was presented to the participant for 2000 milliseconds. After 100 milliseconds, the stimulus would appear with the probe located somewhere along the edge of the stimulus, and would remain upon the screen until a response was made. Once a response was made the background fixation would reappear and the process would begin again. This sequence repeated until the task reached its conclusion.

2.6. Experiment 2a:

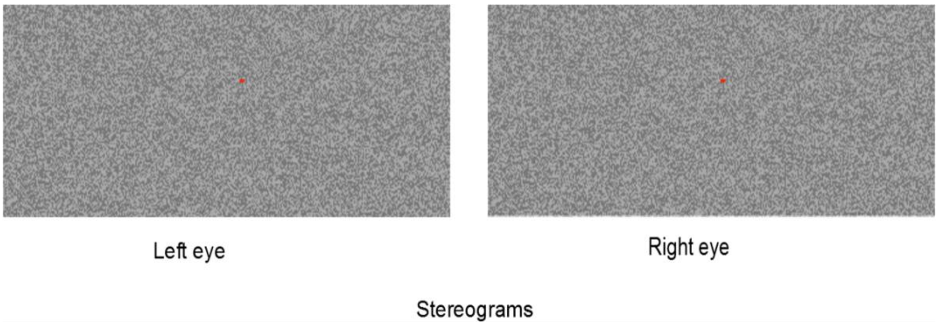


Figure 2.14. Examples of stimuli used in Experiments 2a, 2b, 2c, showing the corner and straight edge for the object and hole conditions (left eye and right eye). No contour appeared in these examples until the participant used the stereogram's glass.

Method

The purpose of Experiment 2a was to test the hypothesis that the corner enhancement effect was present when the targets located in a region of space adjacent to a corner of a new object stimulated enhanced processing, compared with targets presented next to a straight edge.

2.6.1 Participants

Ten students at the University of Liverpool participated, including eight women and two men. Ages ranged from 18 to 22 (*M* = 20 years).

2. 6.2 Stimuli

This experiment used the same stimuli as Experiment 1a (Figure 2.4 and 2.5). It is not manipulated by monocular shading as Exp 1a but it is manipulated by binocular disparity alone, using random dot stereograms (only random dot stereograms isolate disparity as the sole source of depth information).

2.6.3 Results

In addition to the first manipulation of monocular disparity, a second manipulation extended the findings to figure-ground organization specified by binocular disparity alone. It was hypothesised that stimuli positioned relative to a corner (rather than relative to a straight edge) would stimulate more attentional resources, and that relative differences would be seen between concave and convex corners (demonstrated by decreased reaction times). For this condition, shading cues were created using stereograms to create an unambiguous distinction between foreground and background regions.

Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.2% , hole straight is 0.1 %, object corner is 0.3% and object straight is 0.1%. Response times and average error rate are shown in Figure 2.15.

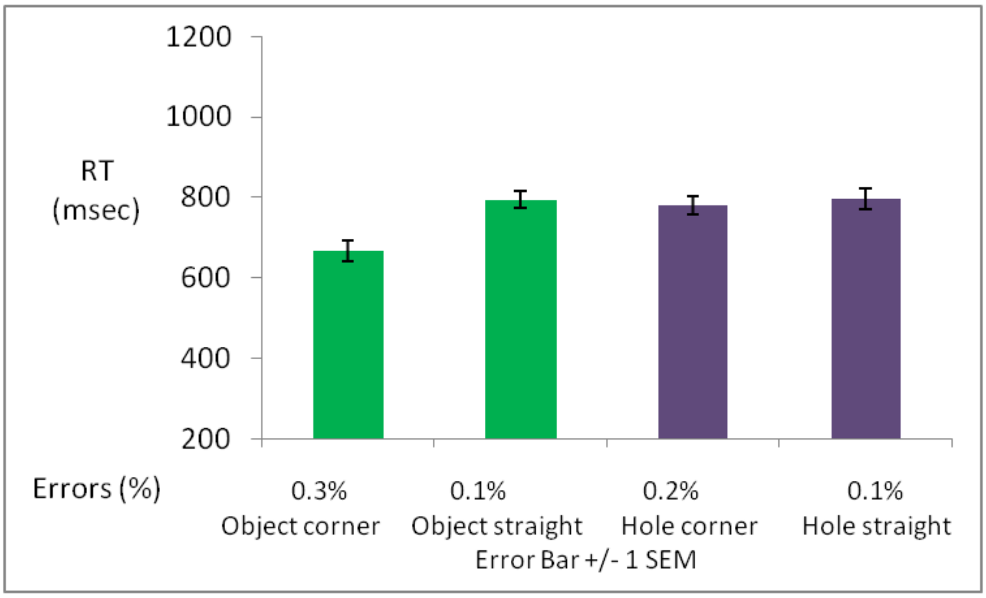


Figure 2.15. Results from Experiment 2a. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

A mixed ANOVA was performed for object (hole or object) and corners (corners or straight edge) as within subject factors and position left and right as a between subject factor. There was a significant effect observed for objectness (F (1, 9) =26.28, p <0.001, partial η^2=0.48); and another significant effect for objectness and corners (F(1,9) = 13.20, p< 0.005, partial η^2=0.48).

To test the corner enhancement effect separately for the hole condition and object condition respectively, a set of t-test were performed. For the object condition, responses were faster in the corner compared to straight position (t (9)=3.33, p = 0.001); and for holes condition there was no difference (t (9) =0.253, p = 0.806 n.s).

These results therefore show that the targets located in a region of space adjacent to the corner of a new object stimulated enhanced processing, in comparison with targets presented next to a straight edge. Furthermore, probes located on top of a surface been demonstrated to have a corner advantage (convex vertices). However, no effect was found for probes located near the corner of a hole. These results are consistent with the results of Experiment 1a.

2.7. Experiment 2b

Method

This experiment is different to Experiment 1b in the location of the target, thus similar to Experiment 1b, this experiment also tested whether targets located in a region of space adjacent to a corner of a new object stimulated enhanced processing, compared with targets presented next to a straight edge.

2.7.1 Participants

Ten students at the University of Liverpool participated, including seven women and three men. Ages ranged from 18 to 22 (M = 20 years).

2.7.2 Stimuli

This experiment used the same stimuli as Experiment 1b (see figure 2.7 and 2.8). In this condition the gray background has corner in the condition in which there is a hole in it.

2.7.3 Results

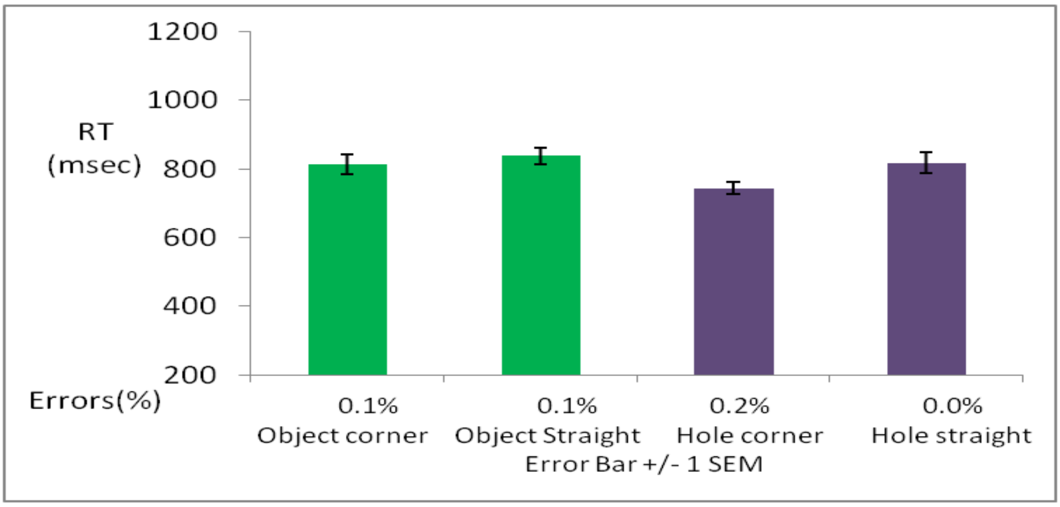


Figure 2.16. Results from Experiment 2b. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

Response times and average error rate are shown in Figure 2.16. Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.2% , hole straight is 0.0 %, object corner is 0.1% and object straight is 0.1%.

A mixed ANOVA was performed for object (hole or object) and corners (corners or straight edge) as within subject factors and position left and right as a between subject factor. There was a significant effect for objectness ($F(1,9)=24.85$, $p<0.001$, partial $\eta^2=0.734$), and another significant effect for objetness and corners ($F(1,9) = 75.41$, $p <0.001$, partial $\eta^2=0.893$).

To test the corner enhancement effect separately for the hole condition and object condition respectively, a set of t-test were performed. For the hole condition, responses were faster in the corner compared to straight position (t (9) =4.04, p= 0.007); and for objects there was no difference (t (9) =-2.02, p= 0.073 n.s).

It has also been demonstrated that holes receive a corner advantage (in terms of processing) when the target probe is perceived as belonging to the surface that owns the corner and in this cases the corner processing is concave vertices. These results are consistent with the results of Experiment 1b.

2.8. Experiment 2c

Method

In Experiment 2c, we tested the hypothesis that corner effects are absent when the probe is not located on top of the surface that owned the surface, but rather on the same depth plane (floating object). Experiment 2a and 2b found a corner enhancement effect for both convex and concave vertices. Experiment 2c involved creating objects that appear to be on the same depth plane. This was done by creating a probe with binocular disparity, which would define it as being different in depth compared to the surface the probe lay on. Perceptually, the probe no longer belonged to any specific surface and would be viewed as floating. Response times and average error rate are shown in Figure 2.17**.**

2.8.1 Participants

Ten students at the University of Liverpool participated in the experiment; all participants were women. Ages ranged from 18 to 22 (*M* = 20 years).

2. 8.2 Stimuli

This experiment used the same stimuli as Experiment 1d (see figure 2.11 and 2.12).

2.8.3 Results

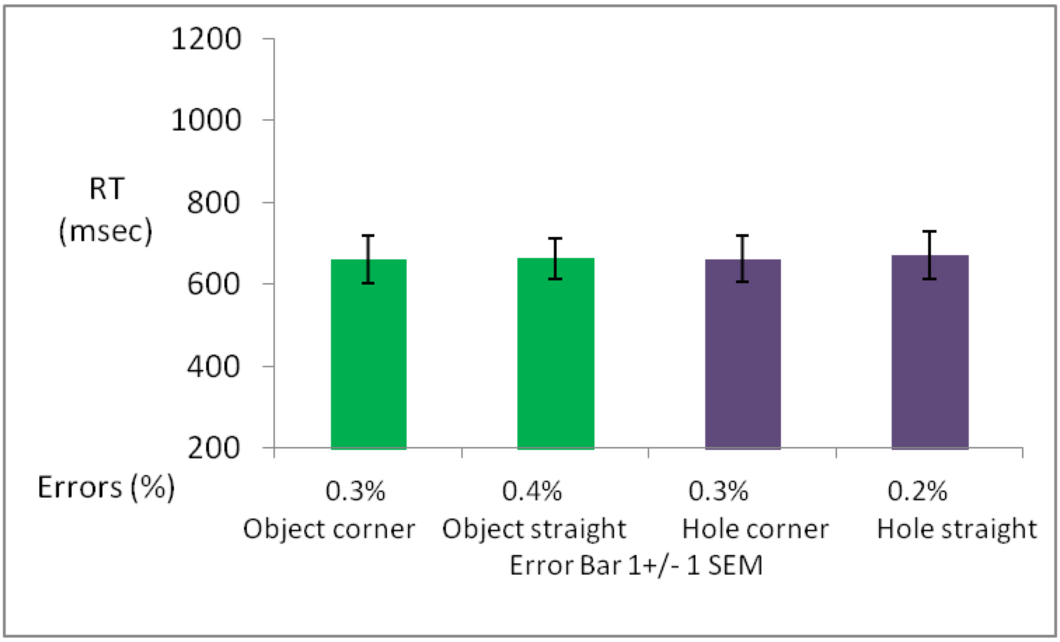


Figure 2.17. Results from Experiment 2c. For each condition the bars show the mean response time for corner and straight edge for both holes and objects. Underneath the bars I also report mean error rate.

Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis, for each condition for hole corner is 0.3% , hole straight is 0.2 %, object corner is 0.3% and object straight is 0.4%.

A mixed ANOVA was performed to compare the effects of object (hole or object) and corner (corner or straight edge) on reaction times for a discrimination task, in a condition where the probe floated above the surface perceived as owning the corner. There was no significant effect for objectness ($F(1,9)=0.03$, $p>0.862$. partial $\eta^2=0.044$), or for corner ($F(1,9)=0.31$, $p>0.590$. partial $\eta^2=0.034$). Neither was there any significant interaction between objectness and corner ($F(1,9)=0.85$, $p>0.378$, partial $\eta^2 = 0.087$).

To test the corner effect for the hole and object conditions separately, a set of t-test were performed. For the holes condition, there was no difference in the corner compared to the straight position ($t(9)=-0.79$, $p=0.44$n.s); and for the objects condition there was no difference ($t(9)=-0.33$, $p=0.73$n.s). The lack of interference for all conditions leads to the conclusion that corner effect cannot be processed independently of the surface belonging to the same depth as the probe.

2.9 General Discussion

The results of this experiment have replicated the finding previously reported by Cole et al. (2001), and additionally contribute a more robust explanation by demonstrating that an advantage of corner enhancement effect is seen only when the probe is located upon the corner-owning surface.

This evidence is consistent with recent claims by Cole, Sakarratt and Gellatly (2007) demonstrating that a target located in a region of space adjacent to a corner (convex vertices) will receive more attentional resources than a target located adjacent to a straight edge. Furthermore, the results of this study support and extend those of Cole et al. (2001, 2007), contributing more robust explanations in terms of convexity and concavity advantage. The present findings show that participants respond better to stimuli near corners rather than stimuli near straight edges, for both convex and concave vertices.

These experiments used a simple task involving the discrimination of orientation for a probe (horizontal and vertical). Coloured regions with cast shadows were used to unambiguously distinguish foreground and background (monocular shading and binocular disparity along with stereograms), as well a square region that could be perceived as either object or hole (a figure-ground reversal). In the object condition, a square surface lay on top of a circular surface, and vertices were consequently perceived as convex. In contrast, in the hole condition, a square hole lay embedded within a circular surfaces, and vertices were consequently perceived as concave.

As expected, the corner enhancement effect was present only when the probe was perceived as belonging to the object/hole surface. For example, the RT taken to detect the probes positioned in a corner location (Experiment 1a and 2a, and Experiment 1b and 2b respectively) was faster relative to probes positioned along the straight edges.

The corner enhancement effect was found to be present for both convex and concave vertices, as long as the probe lay upon the corner-owning surface. Furthermore, the interaction between the corner and the surface disappeared when the probe did not lie upon the corner-owning surface.

This study provided evidence that is consistent with other studies comparing convexity and concavity in the literature. Whilst Koenderink (1990) suggests that convexities tend to be perceived as one of the critical features of an object, the evidence fails to delineate fundamental distinctions with regard to visual processing or sensitivity. Additional criticism argues that cognitive models of shape analysis and representation utilize convexity and concavity information without assigning priority to one of them (Bell, Gheorghiu, & Kingdom, 2009), nor have differences between convexity and concavity has been noticed in studies of adaptation, (Bell, Hancock, Kingdom, & Peirce, 2010). A recent fMRI study has found an advantage for processing convexity over concavity in the anterior lateral occipital complex (Haushofer et al., 2008).

These results are consistent with other studies comparing figure and ground. For instance, Bertamini and Lawson (2008) demonstrated that rapid figure-ground responses for a convex foreground within stereograms when the shape viewed as a convexity (figure). Revealing similar results without the use of stereograms, Driver and Baylis (1995) found that performance was faster and more accurate when the shape used in the experiment was viewed as a convexity (figure) rather than a concavity (ground) (Driver & Baylis, 1995). Other studies (Wong & Weisstein, 1982; Mazza, Turatto, & Umilta, 2005) have demonstrated that faster responses tend to apply to the object condition because of the attentional advantage given to a foreground surface. The results of the present study are consistent with these findings, and additionally contribute a more robust explanation of faster responses to the background region; these findings indicate that the target can belong to either the figure/object region or to the background region, the salient point is whether or not the target is perceived as owning the surface.

The results from this study also demonstrate that an advantage is seen only when the probe is located upon the surface owning the corner. The results further demonstrate a link between the shape of a hole and the shape of an object, and the corner enhancement effect. The corner enhancement effect applies when the probe is located upon the corner-owing surface (i.e. convex vertices when the shape is perceived as a figure/object, and concave vertices when the shape is perceived as a hole). The research literature includes some studies which compare holes and objects, for example Bertamini and Farrant (2006) provided evidence that perceived part structure depends on whether the region is an object or hole.

In summary, the findings reported in Experiment 1b and 2b support findings previously reported by Cole et al. (2001), and demonstrate the link between object or hole (a figure-ground reversal) and corner enhancement effect (for convex and concave regions). Even when a task required discrimination regarding the orientation of the target, the corner enhancement effect was found to apply as long as the target was perceived as belonging to the corner-owning surface; conversely, the effect was not found to apply when this condition was not owns the corner. Finally, these experiments demonstrated that the presence or absence of the corner enhancement effect is effectively determined by which surface owns the probe. This applies regardless of whether the owning surface is perceived as a figure (convex region/object) or background (concave region/hole). If convexities and concavities play a critical role in corner enhancement effect we need to relate this to the question of sensitivity to convexities and concavities information in memory. Consequently, in the second set of studies we investigated visual short-term memory for contour regions perceived either as convex or concave. These experiments specifically test how convexities and concavities are retained in memory.

CHAPTER 3| The role of convexity in visual short-term memory (VSTM)

This chapter is adapted from Bertamini, M. Helmy, M.S., & Hulleman, J. (2012). The role of convexity in perception of symmetry and in visual short-term memory. Quarterly Journal of Experimental Psychology (in press).

Abstract:

Background Visual short-term memory (VSTM) plays an essential role in perception, but the capacity of VSTM is severely limited**.** Specifically, the capacity of VSTM is approximately estimated to be four units. This study intends to investigate the phenomenon of visual short-term memory for convex and concave segments.

Methods Forty participants for each Experiment (9males and 31 females for Experiment 3 and 10 males and 30 females for Experiment 4, except for Experiment 5, which had twenty participants- the mean age is 20 years) were drawn from the student population of the University of Liverpool, either voluntarily or in return for course credit. In this study the units were parts of single objects, created by a simple outline and the segments on the left and on the right could vary in shape. The task was to compare two stimuli before and after a 1000 ms retention interval. In the baseline condition the contour was in isolation. In the convex and concave conditions the closure of the contour made the features either convex (on the outside) or concave (on the inside).

Results There are no differences between storing convex and concave segments in VSTM. In Experiment 3 we found no difference between convex and concave conditions (three and four features), but an advantage for closed contours over the baseline condition. In Experiment 4, we used different procedures: the convex features to be remembered are presented in the second interval as concave features (and the concave features are presented as convex features). We found an advantage for baseline condition over the closed contours. The mixed results between Experiment 3 and Experiment 4 allowed us to conduct another control experiment (Experiment 5). We will focus on the within-subjects effects and exclude between subjects effects because of the large number of subjects.

Discussion The results of this study suggest that the closed contour condition can be found for both convex and concave vertices over the baseline condition; the closed features act as parts; and this will help to store features easily in visual short-term memory. Therefore, there is no difference between convex and concave parts in visual short-term memory.

3.1 Introduction

Working memory is a system that affords storage of information and permits individuals to keep information in mind and utilize it in cognitive tasks. The working memory paradigm classifies working memory into two categories: visual short-term memory, and verbal short-term memory (Baddeley & Hitch, 1974; Logie, 1989). Baddeley and Hitch (1974) have documented a difference between visual short term memory (VSTM) and verbal short-term memory. Therefore, VSTM is a type of short term memory (Phillips, 1974; Baddeley & Hitch, 1974; Cowan, 1998; Oakes, Sheehy, & Luck, 2006; Davis & Holmes, 2005). In this model, the central executive plays a central role to link the short-term memory and the long-term memory systems. This model is not used only in the memory systems but also in cognitive tasks (Baddeley, 1986).

Accordingly, VSTM is defined as short-term memory for storage. Information is retained for a few seconds after it is no longer visible, separately from verbal processing (Luck & Vogel, 1997; Makovski & Jiang, 2007; Olson & Jiang, 2004; Xu, 2002; Song & Jiang, 2006; Lee & Chun, 2001; Davis & Holmes, 2005). Psychologists have discriminated between iconic memory, short-term memory, and long-term memory. There are some features that distinguish VSTM from any other type of memory.

Iconic memory	Visual short- term memory	Long -term memory
• Decays rapidly. • High capacity of storage. • Unable to compare stimuli appear at different locations.	• Decays rapidly after 600 msec. • The storage of capacity is limited to four units . • Able to compare stimuli appear at different locations.	• No decay of information. • The capacity of storage is unlimited. • Retains information for long periods of time extends from minutes to years.

Table (3.1) illustrates the three types of memory (Phillips, 1974; Cowan, 2001; Luck, Vogel, & Woodman, 1997, 2001; Davis & Holmes, 2005).

Subdividing visual short-term memory:

Numerous researchers have made a distinct VSTM in two verbal and visual short-term memory. This distinction is supported by the measurement of neural activity, neuropsychological studies, interference studies and neuroimaging studies. For example, in human neuroimaging studies an area of prefrontal cortex involved in spatial memory systems appear to show delay in both spatial and object memory (Luck & Hollingworth, 2008, Cohen, Perlstein, Braver, Nystrom, Noll, Jonides, & Smith, 1997, Courtney, Ungerleider, Keil, & Haxby, 1996)

Attention plays an important role in perception in general, and in VSTM in particular (Delvenne, Cleeremans, & Laloyaux, 2010; Fougnie & Marois, 2009; Schmidt, Vogel, Woodman, & Luck, 2002. For example, Woodman, Vecera, and Luck (2003) have claimed that objects in a visual scene that are attended to are more likely to be stored in VSTM. This is called inattentional blindness. In relation to the capacity of attention and VSTM, Delvenne (2005) has investigated the capacity of VSTM in the left and right hemi-field. He used the change detection paradigm to estimate the capacity of VSTM in the left and right hemispheres. The stimulus appears in two frames from different hemi-fields or in two frames in the same hemi-fields (left or right). The results revealed that the capacity of VSTM is increased by presenting objects in the left and right hemi-field over one hemi-field This indicates that the storage of VSTM is a consequence of a sequence of capacity-limited operations (Delvenne, 2005).

Makovski and Jiang (2007) have confirmed that attention plays a crucial role in storing and encoding visual information in VSTM, enhancing the ability to focus on the memory items and eliminating the interference on VSTM. When this attention is distributed among the memory items, VSTM is exposed to interference (Makovski & Jiang, 2007). This limitation in VSTM is not due to the inability to use the attention cues, but because of several other elements. For example, Vogel, Woodman, and Luck (2004; 2006) have attributed the limitations of perceptual load, and the long period of time required for consolidation in VSTM, to the fact that it takes 50 msec to encode one item in the memory and this conflicts with other items in memory (Makovski & Jiang, 2007; Vogel et al., 2006).

This is confirmed by both psychological and neuroscience studies. For example, Todd and Marios (2004) have used functional magnetic resonance imaging (fMRI) to demonstrate that the posterior partial cortex plays a central role in VSTM capacity indirectly; for storing representations of the visual world and during retention intervals. This capacity limitation is not due to insufficient time to encode items in VSTM (Todd & Marios, 2004). Interestingly, these findings are consistent with Elliot and Dolan in their study (1998) that elegantly concluded that posterior perceptual regions of the cortex are the key role of the capacity of VSTM. There is a constructive interface between the posterior partial cortex and the capacity of VSTM. Any cortical deficit at posterior brain regions predicts a decreased VSTM capacity (Vogel & Machizawa, 2004).

Courtney et al. (1997) argued that posterior brain regions involved in perception also maintain representations in VSTM (see also; Mitchell & Cusak, 2008; Pessoa et al, 2002; Postle et al., 2003; Todd & Marois, 2004; Agam et al., 2009; Offen et al., 2009; Sauseng el al., 2009).

Psychophysical studies have generally found that the capacity of VSTM is limited to three or four items. However, VSTM capacity is also affected by whether the items can be combined into a single, whole object. For example, Luck and Vogel (1997) found participant's performance declined when the features are isolated, but performance improved when the features join to form a single object. Consistent with this, Song and Jiang (2006) also found that VSTM capacity declined when the complexity of the features increased. Using fMRI, they revealed that activity in many brain regions, such as posterior cortex, the prefrontal region, and the occipitotemporal region deceased with the number of items to be retained, but increased with the complexity of items (Song & Jiang, 2006).

Numerous researchers have found that any deficit of the right frontal cortex reflects the decline of storage capacity of VSTM (Wilson et al., 1987; Phillips, 1974; Alavastos & Milner, 1989; Doyon & Milner, 1991; Xu & Chun, 2006, Xu, 2007). Participants with frontal cortex impairments are slower to respond and take more time to encode items in VSTM than normal participants or participants with temporal –lobe impairments (Pigott & Milner, 1994). These findings are consistent with Xu and Chun (2006) who claim that the inferior partial sulcus (IPS) is the brain region that mediates

VSTM most directly. They concluded that frontal and prefrontal cortex processing can increase the capacity of VSTM (Xu & Chun, 2006; Xu, 2007).

A direct measure of representation in VSTM is difficult. Given this, the most popular device to measure the representation in VSTM is a change detection task (Luck & Vogel, 1997; Rensink, 2002; Simons & Rensink, 2005; Olson & Jiang, 2004; Philips, 1974; Luck & Vogel, 1997; Wilken & Ma, 2004; McCullough, Machizawa, & Vogel, 2007; Jiang, Chun, & Olson , 2004). There are two types of change detection task, one based on change detection and one based on successful tracking. The *first paradigm* has two conditions: *one-shot change detection* and *flicker change detection*. In the one-shot detection task, participants view a sample array; after a retention interval there is a second presentation. The participants compare the first presentation and the second presentation. The participants must detect any difference between first and second presentation. In 50% of the trials there is a change, in 50% of the trials the stimulus remains the same without any change (Luck & Hollingworth, 2008; Olson & Chun, 2004). In a flicker change detection task two versions of the stimulus are presented on the screen with a blank screen in between. The presentation repeats on the screen until the observers make their response; the participants must detect any change from first interval to the second interval (Luck & Hollingworth, 2008).

The *second paradigm* to assess the capacity of VSTM is *Multiple Object Tracking (MOT)* (Pylyshyn & Storm, 1988; Scholl & Pylyshyn, 1999; Yantis, 1993). Here, participants track a number of moving objects (some of which are labelled as targets). After a short period of time, the stimulus stops moving and participants indicate which stimulus were the targets (Delvenne, 2005).

3.1.1 The capacity of VSTM

Capacity is defined as the amount of information that can be supported in memory at one time. The capacity of VSTM is an important issue in the literature. Many researchers (for example; Nickerson (1965); Baddeley (1986); Logie et al.(1990); Schweickert & Boruff (1986); Walker et al (1993); Alvarez & Cavanagh (2004); Cowan (2001); Jiang, Olson, & Chung (2000); Luck & Vogel (1997); Pashler (1988); Logie (1989); Philips (1974); Avons & Phillips (1987); Lisman & Idiart (1995); Lee & Chun (2001); Olson & Jiang (2004); Olsson & Poom (2005); Eng, Chen, & Jiang (2005); Awh, Barton, & Vogel (2007); Vogel, Woodman & Luck (2006); Curby & Gauthier (2007); Makovski & Jiang (2008); Rouder et al (2008); Luck & Hollingworth, 2008; Brady, Konkle, & Alvarez (2008); Alvarez & Cavanagh (2008) have claimed that the VSTM has a capacity of four objects or chunks of information, and capacity depends upon how items or objects are presented and how items or chunks are encoded in memory (Cowan, 2001; Ross-Sheehy, Oakes, & Luck, 2003; Kumar & Jiang, 2005; Fougine & Marois, 2006).

The estimated capacity of VSTM developed from signal detection theory because SDT is very useful to measure memory performance in different conditions (Macmillan & Creelman, 2005); a formulation has been developed to estimate VSTM capacity depending upon change detection theory. This incorporates the measure of sensitivity to any change occurring between presentations (D prime); “yes” means “different, whilst “no” means “the same”. Signal detection theory is widely accepted to measure sensitivity and implicates responses to both sensitivity and bias. Bias must be considered to recover sensitivity, but sensitivity itself is the factor we want to test. D prime is formulated below: ($d' = z(H) - z(F)$). Where H is the hit rate (rate of correctly reporting a change), FA is the false alarm rate (rate of incorrectly reporting a change). D prime as a statistic is a measure of the distance between (signals) to (signal+noise). D prime is a standard tool to estimate sensitivity, and a higher D prime suggests a signal that is more easily detected (Macmillan & Creelman, 2005; Alvarez & Cavanagh, 2008).

Furthermore, response bias is defined as the tendency of an observer to give either a positive or a negative response. The response bias measure (*c*') is a function of H + F. This depends on both the hit rate and false alarm rate in the same direction, either increasing or decreasing in both. Therefore, sensitivity measures become higher with H and lower with F; on the other hand c' shows either the degree to which positive or negative responses dominate responses (Macmillan & Creelman, 2005).

Luck and Vogel (1997), Pashler (1988) and Philips (1974) describe the change detection paradigm as a standard tool to measure VSTM. This capacity has the same limitation when participants are remembering a single feature or multiple features. This is consistent with Delvenne and Bruyer (2004) who concluded that participants can retain three to four objects. Saiki and Miyatsuji (2009), taking the same approach of Luck and Vogel (change detection paradigm) found that capacity of VSTM is estimated to the same limit of items: three to five; this limitation is attributable to the maintenance of the VSTM, not retrieval cueing (Sakiki & Miyatsuji, 2009). Furthermore, VSTM plays a key role in memory of 3-D surfaces; participants hold more information in VSTM when the objects belong to the two parallel 3-D rather than the same 3-D. The presence of 3-D surfaces affects both perception and short-term memory, demonstrating that we can take the benefit of 3-D surfaces and use it to systematize object representation in VSTM (Xu & Nakayama, 2007). Thus, Luck and Vogel (1997) have shown that Change detection paradigm is a good tool to study VSTM and visual attention (Luck &Vogel, 1997, Rensink, 2002; Luck & Hollingworth, 2008).

Some researchers have claimed that the capacity of VSTM is related to a fixed number of units regardless of complexity (Awh, Barton, & Vogel, 2007). Furthermore, there are other factors that contribute to the storage capacity of VSTM. Accordingly, capacity of VSTM for complex and simple objects is homogenous in working memory (Awh et al., 2007).

In contrast, Alvarez and Cavanagh (2004) have concluded that there is a relationship between complex stimuli and the number of objects that can be held in VSTM. They mixed complex and simple stimuli, for example letters, colours, polygons, and Chinese characters. The results showed that the capacity of VSTM declines when complexity increases object: the greater the stimulus complexity, the smaller the VSTM capacity. Similar results have been found in other studies (Makovski & Jiang, 2008; Eng, Chen, & Jiang, 2005).

Furthermore, Olson and Jiang (2004) have suggested that VSTM has the same capacity of units although they used the repeated the objects several times to increase the storage of VSTM. They found after a series of experiments that the VSTM performance for no-repeated stimuli was higher than for repeated stimulus. This stability of VSTM capacity demonstrates that the capacity of VSTM is unaffected by practice. They used a stimulus that appeared for 500 msec, disappeared for 250 msec, and then reappeared. Subjects judged whether the cued location of the stimuli matched the memory locations. The configuration was repeated and subjects judged whether the stimulus was from the previous configuration. The study indicates that capacity of VSTM is limited to four units, although the researchers used a repeated mechanism. This provides and easily encodes and stores information in visual long-term memory (VLTM) (Olson & Jiang, 2004).

Other researchers have investigated whether the capacity of VSTM is influenced by training or experience. For example, Curby, Glazek, and Gauthier (2009) investigated the effect of training on VSTM for objects. They suggested that the capacity of VSTM is three to four objects and this is not improved by experience (Curby et al., 2009). These findings are consistent with Eng Chen, and Jiang (2005) and Moore, Cohen, and Ranganath (2006).

Moreover, numerous researchers (Ross-Sheehy, Oakes, & Luck, 2003; Rose, Feldman, & Jankowski, 2001; Oakes, Sheehy, & Luck, 2006) have tested whether infants have the same capacity storage as adults. They found after a series of experiments that infants from 4 to 13 months of age have the same storage capacity and have the ability to encode and retain the visual stimulus presented. They used the paradigm that Luck and Vogel (1997) used for adults. They used a stimulus which was presented for 500 msec, and hidden for 250 msec, and was presented on the right and on the left side in intervals. The study indicates that infants have the ability to recognize the changing stimulus, and that capacity of VSTM improves over the first year of life. Furthermore, infants' capacity storage of VSTM is essentially limited to three or four items by the end of the first year (Sheehy et al., 2003; Rose et al., 2001; Oakes et al., 2006). These findings are consistent with Riggs, Taggart, Simpson, and Freeman (2006), Saults and Cowan. (2007), Cowan, Elliott, Saults, Morey, Mattox, Hismjatullina, and Conway (2005) who claim that growth of VSTM capacity are related to age. They used the Luck and Vogel change detection paradigm, with some adjustments. They changed the instruction to be appropriate for the children, expanded the time of stimuli presentation from 250 msec to 500 msec, and extended the age range for example, from 1-5 to 1- 10years old. It is plausible that VSTM develops between 6 and 10 months of age and the time required to bind the VSTM differs from the time required to bind the long-term memory. 6 to 9 months is the ideal period to bind the objects and the location in VSTM (Oakes, Ross-Sheehy, & Luck, 2006). More importantly, the youngest children have suffered from following the instructions of the experiment and to encode the information (Riggs et al., 2006; Cowan et al., 2005). These findings were consistent with Pickering (2001), and Ang and Lee (2010) who have confirmed that older children for example, 11 years old performed better than younger children for example, 8 years old in both VSTM and in working memory tasks. They used the dual task paradigm, in which participants perform two tasks together (e.g. random number generation and visual short- term memory) and found that older children have the ability to chunk different parts in VSTM in contrast to younger children (Pickering, 2001, Ang & Lee, 2010).

3.1.2 The units of VSTM

The literature offers two conflicting perspectives concerning the units of VSTM and the number of objects or features. Philips (1974); Pashler (1988); Luck and Vogel (1997); Vogel, Woodman, and Luck (2001); Mitchell and Cusack (2007) and Woodman and Vogel (2008); Jiang, Makovski, Shim, and Brockmole, (2009) have demonstrated that integrated objects are encoded more easily in VSTM than other features. Moreover, the features are encoded in the VSTM only if they form the same part of an object (Xu, 2002; Olson & Jiang, 2002). Researchers have made considerable progress in understanding the units of VSTM for example, Xu, 2002; McCollough, Machizawa, & Vogel, 2007; Woodman & Vogel, 2008; Zhang & Luck, 2008; Johnson, Hollingworth & Luck, 2008) have concluded that the units of VSTM is objects rather than features.

Philips (1974) and Avons and Philips (1980) have developed the matrix technique to assess the capacity of VSTM for patterns. After a series of experiments, they concluded that the necessary time to encode the items in VSTM is smaller than

0.25 sec. The capacity of VSTM increased when passive processing was required; for example reading digits; and the capacity of VSTM decreased when active processing was required. They concluded that the capacity of VSTM was not affected by masking or by increasing the duration of the stimulus (Philips, 1974; Avons & Philips, 1980; Pigoot & Milner, 1994).

Xu (2006) has demonstrated that it is easier to remember two features belonging to the same object in visual short-term memory, than to remember two features belonging to spatially separated objects. The units of information stored in VSTM are objects. For example, features of an object that are connected and share common parts are easier to remember than features not connected to each other. Alvarez and Cavanagh (2004) have found that the capacity of VSTM is limited not because of the number of objects, but because of the nature of the visual information stored (Alvarez & Gavanagh, 2004; Xu, 2006). It is easy to encode information in VSTM from the same part of an object, and not easy to encode information belonging to different parts. It remains conceivable that the storage of information is related to the compound parts of objects (Xu, 2002).

Luck and Vogel (1997) have made considerable progress in understanding the capacity of VSTM for features and conjunctions. They concluded that observers store integrated objects rather than features. Moreover, they concluded that VSTM is not affected by lack of perception, encoding, or verbal memory. They found that there was no advantage for adding verbal stimuli. In a further investigation they varied the duration of the stimulus; for instance, the presentation duration increased from 100 msec to 500 msec to allow the observers enough time to perceive the stimuli and encode the memory. Results indicated that there was no difference in performance between the 100 msec and 500 msec. Capacity remains 4 units only. Finally, they measured VSTM capacity with altered dimensions of colour and orientation. Different orientations should lead to improved performance and results indicated that although the stimuli had different dimensions, performance was still the same and the storage capacity is four units in VSTM. From this series of experiments, Luck and Vogel have concluded that there is no effect of verbal loading, varied duration, and different dimensions to the capacity of VSTM (Luck & Vogel, 1997).

Lee and Chun (2001) have demonstrated that VSTM is composed of objects, and every object has manifold features. This study also showed that the number of features of each object is not relevant and does not affect VSTM capacity. This demonstrates that VSTM units were enlarged beyond normal proprieties of features (Luck & Vogel, 1997; Luck, Vogel, & Woodman, 2001. Conversely, updating objects in VSTM by adding up or removing new information is a feature, not an object, and is not inhibited by the limits of short-term memory capacity (Ko & Seiffert, 2009).

On the other hand, numerous researchers (Stefurak & Boynton, 1986; Wheeler & Treisman, 2002; Delvenne & Bruyer, 2004) have argued that the capacity of VSTM correlates with the number of features in different dimensions. The capacity of VSTM for features belonging to different dimensions is very high compared to features belonging to the same dimensions, because features belonging to the same dimensions interfere with each other. Indeed, features from the same dimensions compete for the capacity of VSTM, whereas features from distinct dimensions are considered in relation to the capacity of VSTM (Delvenne & Bruyer, 2004).

Sakai and Inui (2002) have concluded that the same capacity limitation applies to convex parts (i.e. convex segments of a closed contour). They proposed a new model of VSTM. This model relies on a signal detection theory (SDT), and on dividing the contour into two regions: convex and concave. They tested the convex parts only. They used a stimulus which appeared for 360 msec, and disappeared for 720 msec, and finally reappeared. Subjects judged whether the first and the second presentation were the same or different. According to the authors, depending on the complexity of patterns, VSTM has a capacity of four convex parts and is retained in the memory more easily; and performance descended significantly as time exposure decreased. In consideration of these findings, it is reasonable to point out that the decay rate is weakened for longer exposure durations and the pre-eminent time to encode the features is 300 msec (Sakai & Inui, 2002).

3.1.3 Comparing convexity and concavity.

In the literature there have been claims that the detection of a change in a concavity is easier than the detection of a change in a convexity (Cohen et al., 2005). However, Bertamini (2008) has argued that all evidence is consistent with the fact that detection is easier only when part of the structure changes, and this happens when a region is changed from convex to concave or vice versa, whilst there is no difference in a direct comparison of changes within a convex region or a concave region (Bertamini, 2008). However, a privileged coding of convexity (higher sensitivity in LOC) has been reported in a recent fMRI adaptation study (Haushofer, Baker, Livingstone, & Kanwisher, 2008).

For the first time, we directly compare convex and concave segments of a contour in a standard VSTM task. Although this has not been done before for VSTM, there is evidence that convexity is more important in tasks like symmetry detection (Hulleman & Olivers, 2007). It is been shown that it is easier to detect deviations from symmetry when the regions that specify the asymmetry are convexities and it is harder to detect deviations from symmetry when the regions that specify the asymmetry are concavities. This is the case even when the convexities are near the axis of symmetry and the concavities are far from the axis of symmetry (Hulleman & Olivers, 2007).

Furthermore, Bertamini (2001) has reported a convexity advantage in a task in which participants were faster at judging the position of convex stimuli than concave vertices. He speculated that this was due to the fact that convex vertices define parts of solid objects, and parts are perceived as having a position (Bertamini, 2001). On the other hand, concave vertices are perceived as boundaries between parts. So, positional information is more directly involved with convex regions.

As we mentioned earlier, one study has investigated the role of convex regions in VSTM. Sakai and Inui (2002) have shown that the limitation in capacity of VSTM applies to convex parts (i.e. convex segments of a closed contour). Furthermore, retention of visual information became more easily when the curvature of the contour belongs to convex regions and that retention of information applies to four convex segments (Sakai & Inui, 2002).

There have also been reports of a concavity advantage in change detection (Barenholtz et al., 2003). It has been proposed that concavity plays a more important role than convexity in shape perception. Concave vertices can be easily detected in visual displays. For instance, the search for a concave target among convex stimuli is more efficient and accurate than the search for a convex target among concave stimuli (Hulleman et al., 2000; Humphreys & Muller, 2000; Wolfe & Bennett, 1997; Bhatt et al., 2006). However, this may have been a consequence of a change in perceived part structure. All subjects were tested in a change detection task because this technique is the most widespread task used in the behavioural studies of VSTM (Vogel & Luck, 1997).

In my second set of studies we used stimuli similar to those used in the first series, but the task was more similar to that used in Bertamini (2008) and in Cohen et al. (2005). However, unlike previous studies we increased the retention interval to 1 second (1s), to be more consistent with the classic paradigm used to study visual short-term memory (Luck & Vogel, 1997; Luck, Vogel, & Woodman, 2001). We also used a set of 3 or 4 features to be remembered, because this is the limit of visual short-term memory. It is possible that having to perform at the limit of the short-term memory capacity will reveal a difference that may not be present for tasks with fewer features and shorter retention intervals. Before describing the details of our experiments, we will list all of the experiments we have run in VSTM (Table 3.2).

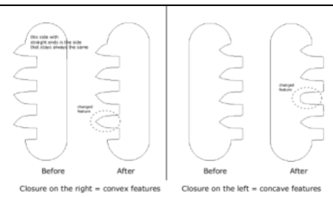
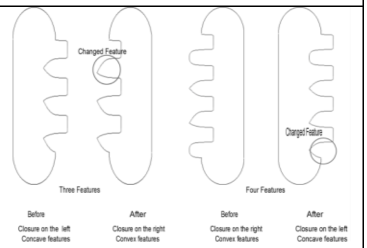
Experiment title	Experiment aim	Stimuli
(3)Three and Four Features.	To test the difference between convexity and concavity in a predictable location for three and four features.	
(4)Change polarity three and Four Features.	To test the effect of change polarity (the contours closed to form an object changed from the first to the second interval) for three and four features in VSTM.	

Table (3.2) illustrated the VSTM experiments. In Experiment 3 we test the difference between convexity and concavity in three and four features. Whereas in Experiment 4 we test the change polarity (the contours closed to form an object changed from the first to the second interval) for three and four features.

3.2 Experiment 3

Method

The purpose of Experiment 3 is to test the difference between convexity and concavity in a predictable location for three and four features in VSTM.

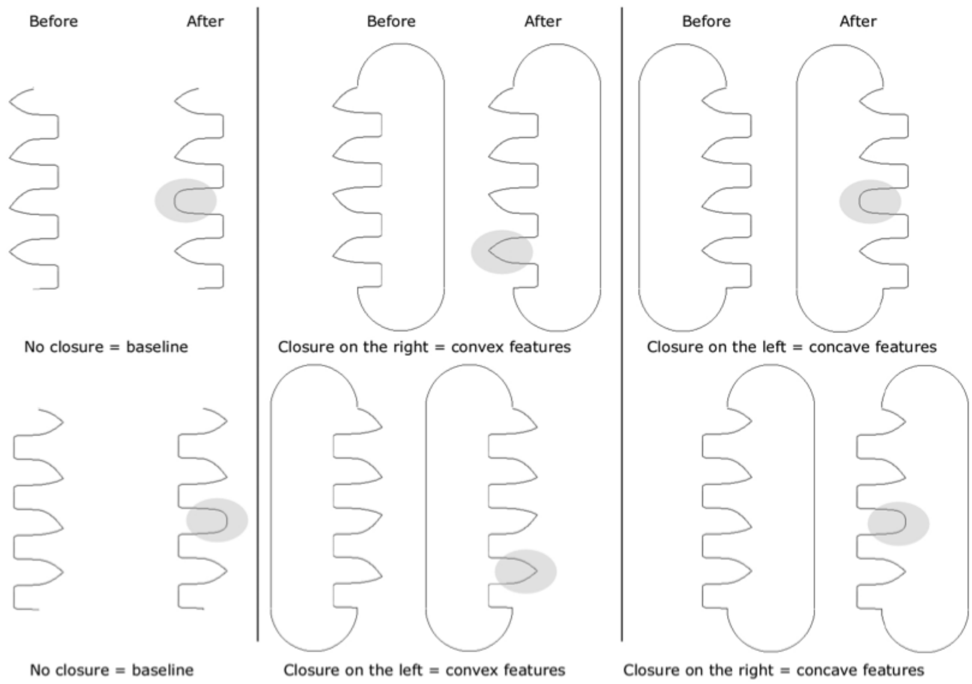


Figure 3.1. Example of stimuli used in Experiment 3. The contour with four features was presented in a fixed position throughout a session. Without closure (baseline condition) the convexity or concavity of this contour was ambiguous. In the convex condition a curved contour provided closure on one side (right in this example) and in the concave condition the contour provided closure on the other side (left in this example).

3.2.1 Participants

Forty members of the University of Liverpool community took part in the study (mean age 20 years, 9 males and 31 females were involved). Half were assigned to the four features condition and half to the three features condition. Within each condition for half of the participants the features to be monitored were on the right of the features that did not change and for the other half they were on the left.

3.2.2 Stimuli

Observers were asked to compare a stimulus before and after a 1s retention interval. The stimulus was presented for 1.6 s followed by a 1s of blank screen. The second presentation appeared on the screen until the participants responded by judging whether the shape was the same or not. In some trials the change was in the convex features, in other trials it was in the concave features. The features were concave when they were on the right and the object was closed on the right, or they were on the left and the object was on the left. If features and object were on different sides the features were convex. Examples of the stimuli are illustrated in Figure 3.1., the stimuli were presented on a monitor (resolution 1024X 768 at 85 Hz) controlled by an Apple Macintosh computer. The actual position of the stimulus was randomly varied in each trial around the centre of the monitor to discourage observers from using positional cues.

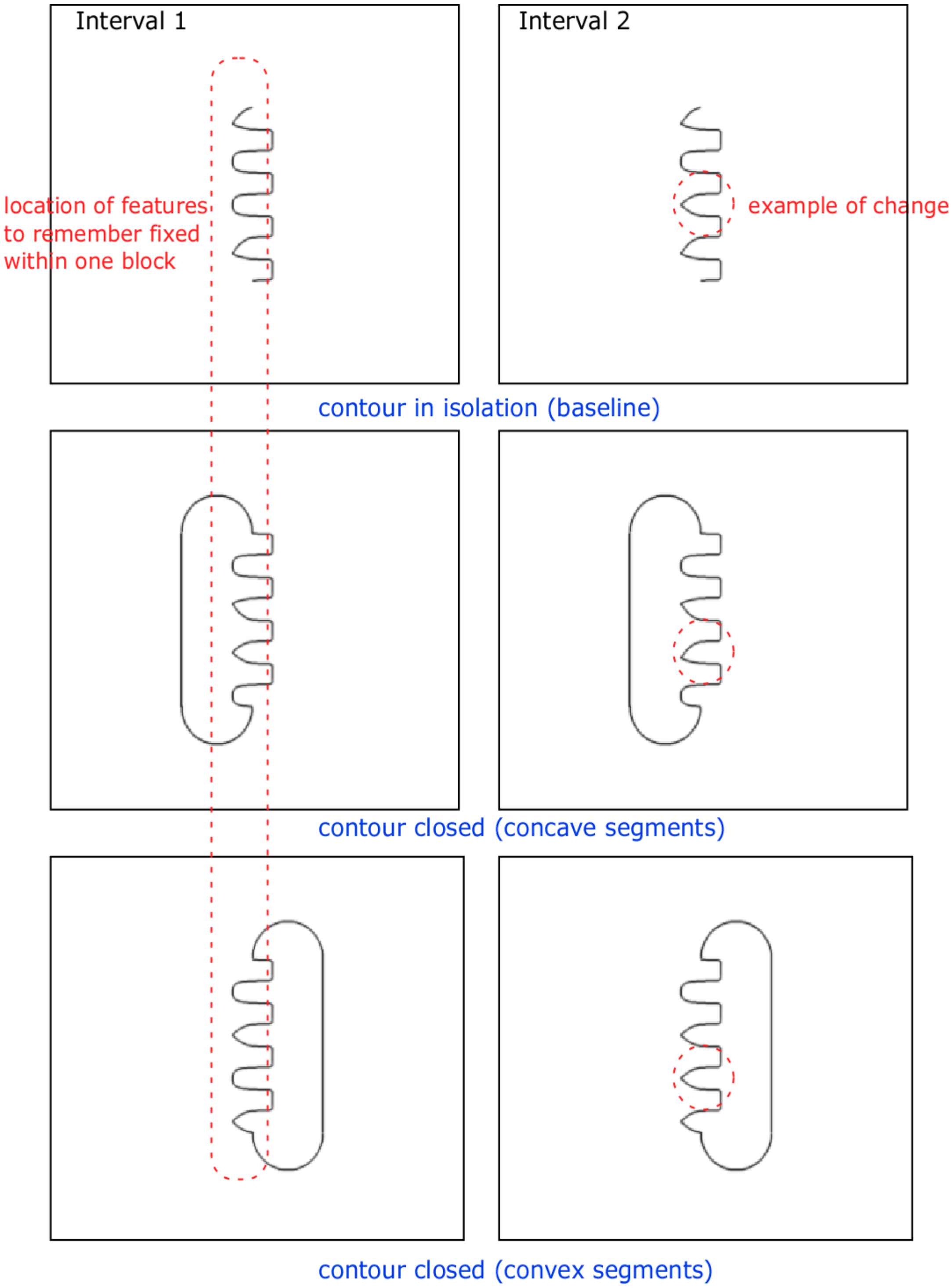


Figure 3.2. Example of stimuli used in Experiments numbers illustrated changed features from first interval to second interval.

3.2.3 Results

Our first ANOVA tested the difference between the convex and concave conditions. In the mixed design we included convexity (convex and concave) as a within-subjects factor, number of features (three and four) and position (left or right) as between-subjects factors. There was no a significant effect or interactions. For example, there is no significant interaction between convexity (Convex and concave) and number of features and the position (left and right) (F (1,36) =0.49, p = 0.48, partial η^2 =0.014).

In a second analysis we compared the baseline condition in which the contour was not closed with the closed object, i.e. the average of convex and concave conditions. The design was the same as the first analysis except that closure (open and closed) replaced convexity. We found a significant effect of closure (F(1,36)=4.71, p =0.037, partial η^2= 0.12). Observers performed better for closed shapes compared to the baseline condition. Closure enhances shape detection (Elder & Zucker, 1993) and modulates shape adaptation (Bell, Hancock, Kingdom & Peirce, 2010). Our data is therefore consistent with previous literature.

The same analyses that were performed on d prime were also performed on a measure of bias. We used the standardised c criterion. The size of the bias was small and there were no significant effects or interactions. For example, there are no significant interactions between convexity (convex and concave) and as a within-subjects factor, number of features (three and four) and position (left or right) as between-subjects factors (F(1,36)=*0*,12, p=0.72, partial η^2 =0.004). Also, there is no significant interaction between baseline and closed condition (F (1,36) = 0. 42, p = 0.52, partial η^2 = 0.012).

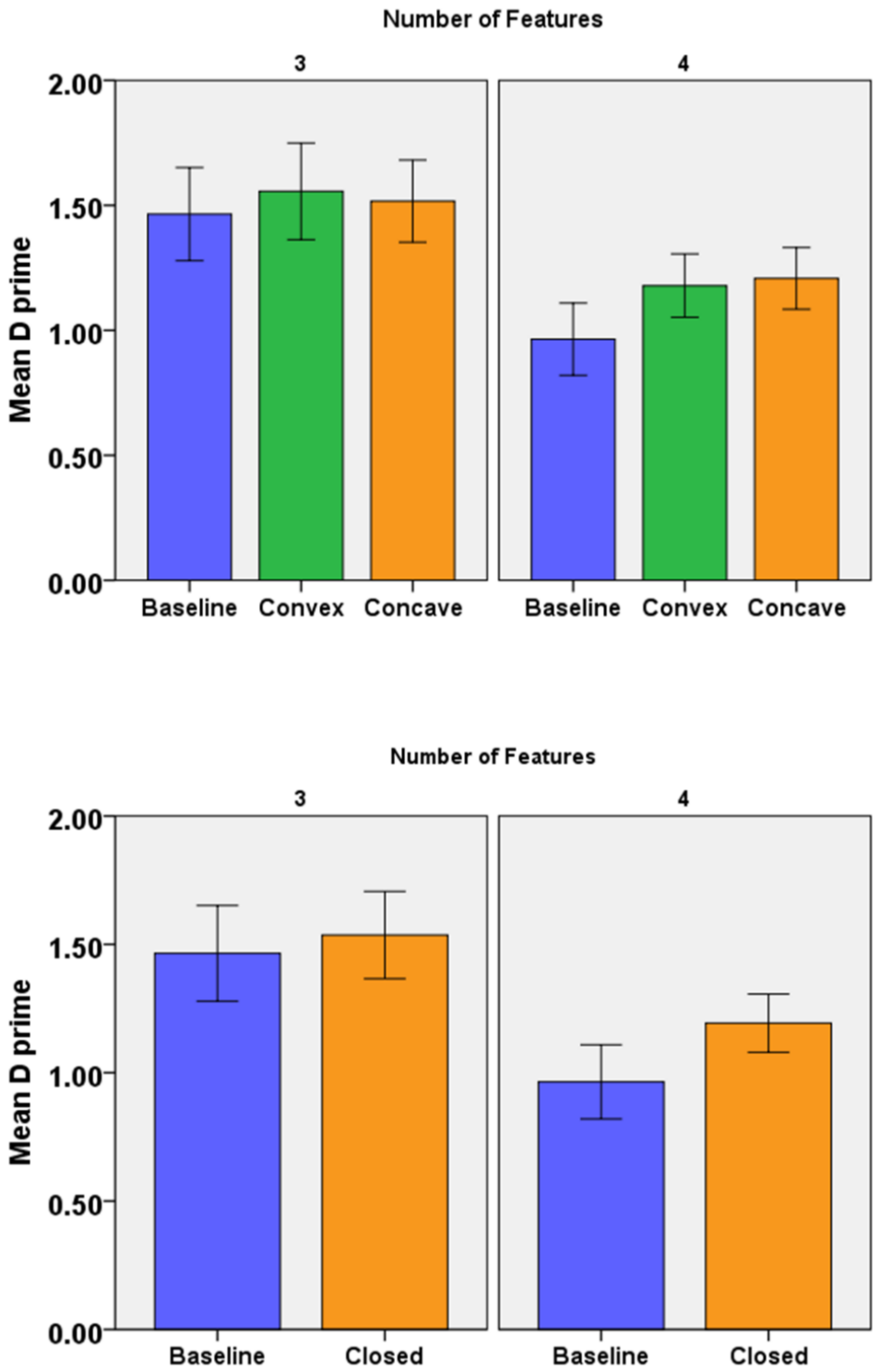


Figure 3.3. Sensitivity d prime for baseline, convex and concave (top row) and sensitivity d prime for baseline and closed condition (bottom row) includes both convex and concave stimuli because there was no significant difference between these two. Error bars are ± 1 SEM.

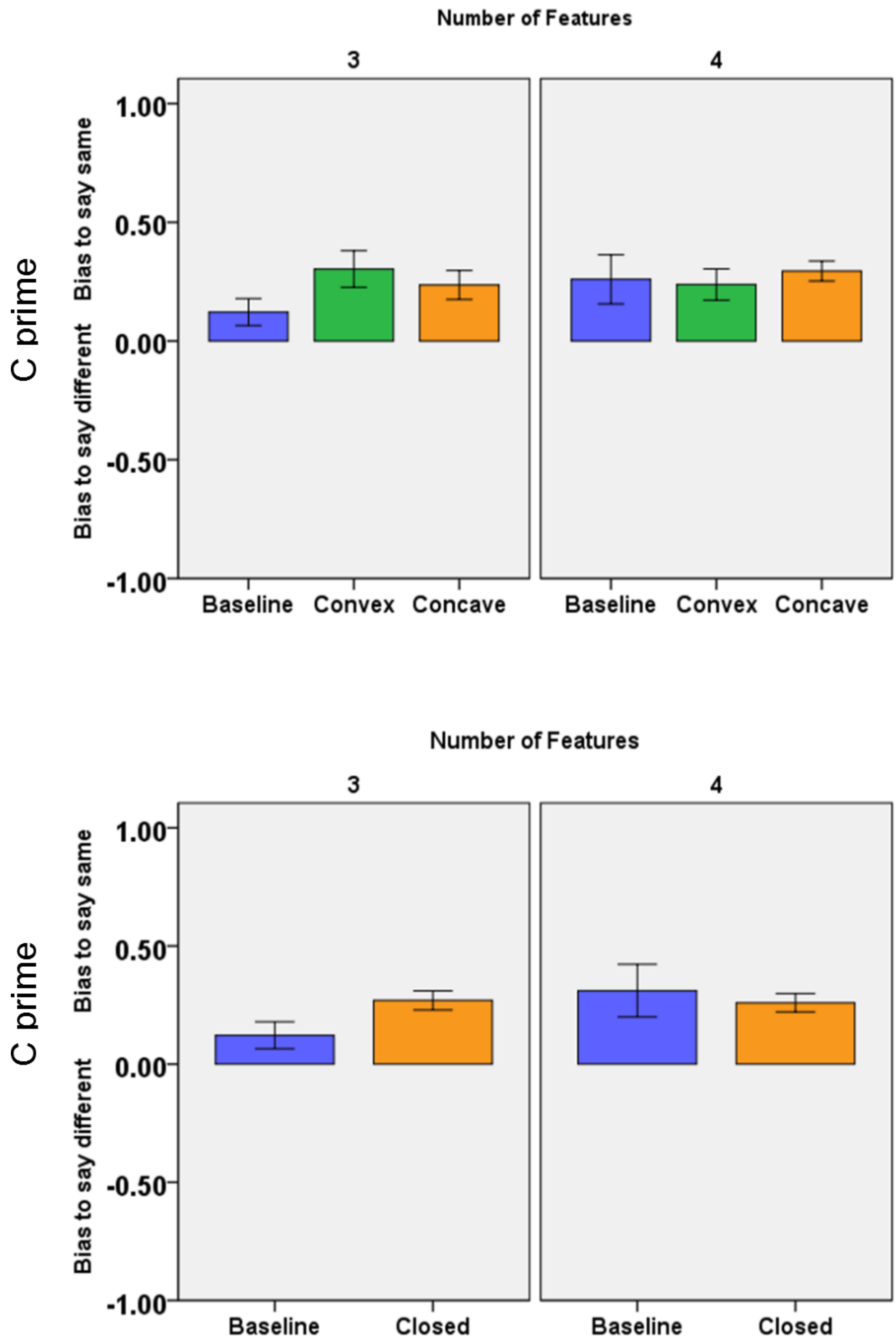


Figure 3.4. Response Bias for baseline, convex and concave (top row) and mean bias (c prime) for baseline and closed condition (bottom row) includes both convex and concave stimuli because there was no significant difference between these two. Error bars are ± 1 SEM.

3.2.4 Discussion

Experiment 3 demonstrated that performance improved during detection of changes to convex or concave features compared to detection of changes to the baseline open contour, although there was no difference between detection of changes to either convex or concave features. This can be interpreted in two different ways. This may support the theory that closure improves shape processing. Aforementioned feature-detection studies have generally found that closed contours facilitate faster and more accurate shape processing compared when features are isolated (Elder &Zucker, 1993; Kovacs & Julesz, 1993). They found that participant’s performance declined when the features were isolated, but performance improved when the features were inside a closed contour. Participants were asked to detect a target inside a closed contour and outside non-closed contour (baseline condition) and it was concluded that closed contour is a key factor facilitating shape processing (Elder &Zucker, 1993; Kovacs & Julesz, 1993).

Firstly, a potential explanation is that the spreading of attention is partially confined to a small area of space by the surface present for the closed objects. A second possible resolution is that interpretation of convexity and concavity may have changed from one interval to another because the contour in the baseline condition was ambiguous in this respect. This may result in the perception of change in the absence of change. This would suggest a higher bias in the negative condition to respond differently. However, there was no evidence of this. Nonetheless, the ambiguity of the contour may have been one factor in increasing difficulty of the task.

3.3 Experiment 4 (Memory for features with a change in convexities and concavities)

Method

The purpose of Experiment 4 is to test the effect of change polarity (the contours closed to form an object changed from the first to the second interval) for three and four features in VSTM.

Experiment 4 differs from Experiment 3 in that the contours which were closed to form an object changed between interval one and interval two. Observers were exposed to convex features and then concave features (or vice versa), interval by interval, and had to detect any change between the two. If the advantage in Experiment 3 was not reproduced in Experiment 4, this would suggests that the Experiment 3 advantage was not only a consequence of closure or due to the closed objects being small surfaces. Additionally this advantage would be removed by the change between intervals if coding of convexity and concavity is a factor. Suppose that for fifty percent of the trials in the baseline condition what was perceived as convex was changed to be perceived as concave and vice versa; if the switch in convexity was responsible for the relatively poor performance of observers in the baseline condition; the closed condition in Experiment 4 could lead to a performance below baseline, as in some trials the coding in the baseline condition would remain the same by chance.

3.3.1 Participants

Forty members of the University of Liverpool community took part in the study (mean age 20 years, 30 female were involved). Half were assigned to the four features condition and half to the three features condition. Within each condition for half of the participants the features to be monitored were on the right of the features that did not change and for the other half they were on the left.

3.3.2 Stimuli

Observers were asked to compare a stimulus before and after a 1s retention interval. The stimulus was presented for 1.6 s followed by a 1s of blank screen, and then the second presentation appeared and remained on the screen until the participants responded. Observers judged whether the shape was the same or not. In some trials (50%) the change was in the convex features, in other trials it was in the concave features. The features were concave when they were on the right and the object was closed on the right, or they were on the left and the object was on the left. But, if features and object were on different sides the features were convex. Examples of the stimuli are illustrated in Figure 3.5. The stimuli were presented on a monitor (resolution 1024X 768 at 85 Hz) controlled by an Apple Macintosh computer. The actual position of the stimulus was randomly varied in each trail around the centre of the monitor to discourage observers from using positional cues.

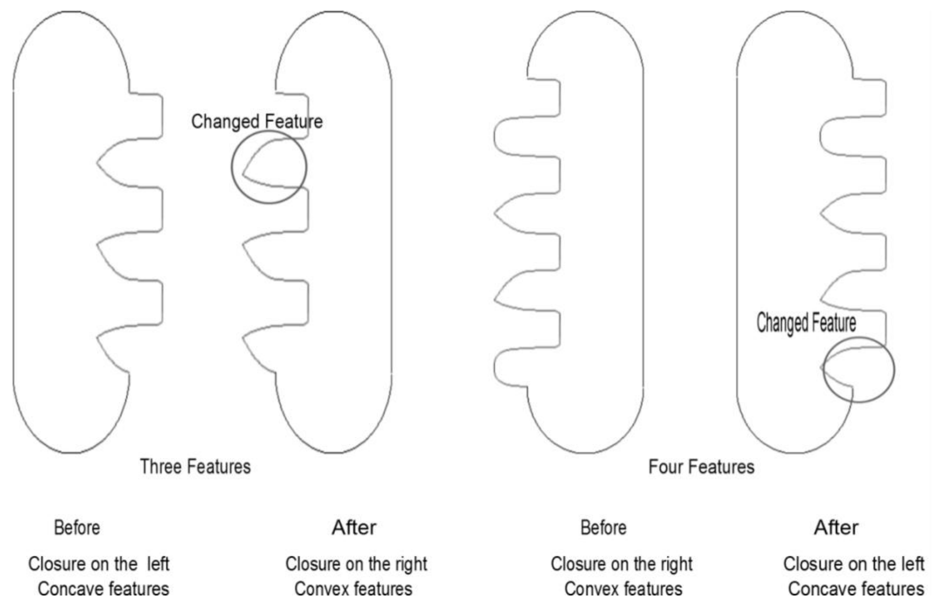


Figure 3.5. Example of stimuli used in Experiment 4. The contour with three features and four features were presented in a fixed position throughout a session. Concave in the first interval to convex in the second interval in the Three-features condition and changes from convex in the first interval to concave in the second interval in the Four-features condition.

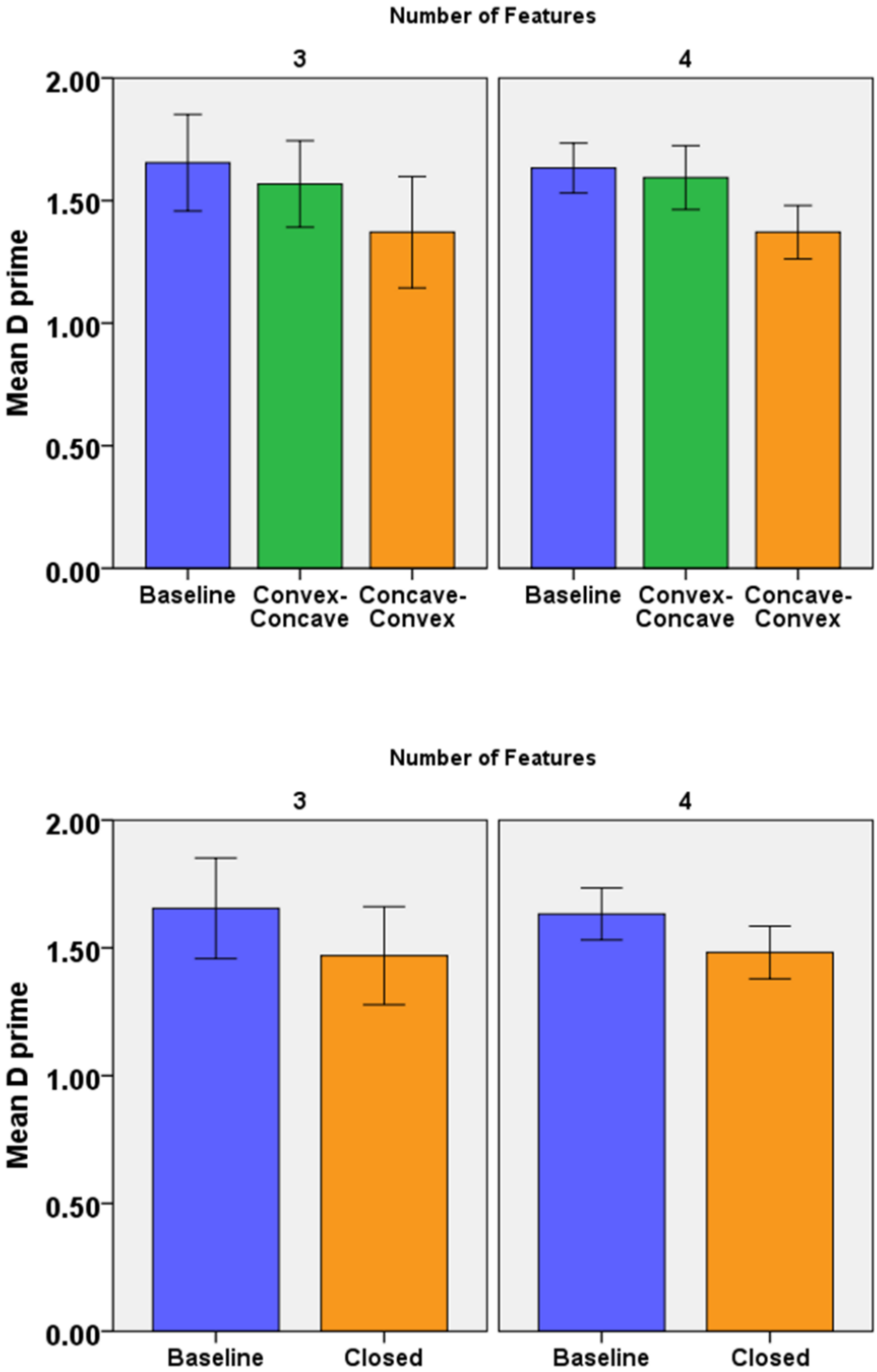


Figure 3.6. Sensitivity d prime baseline, convex and concave. (Top row) and sensitivity d prime for baseline and closed condition closed condition (bottom row) includes both convex and concave stimuli. Error bars are ± 1 SEM.

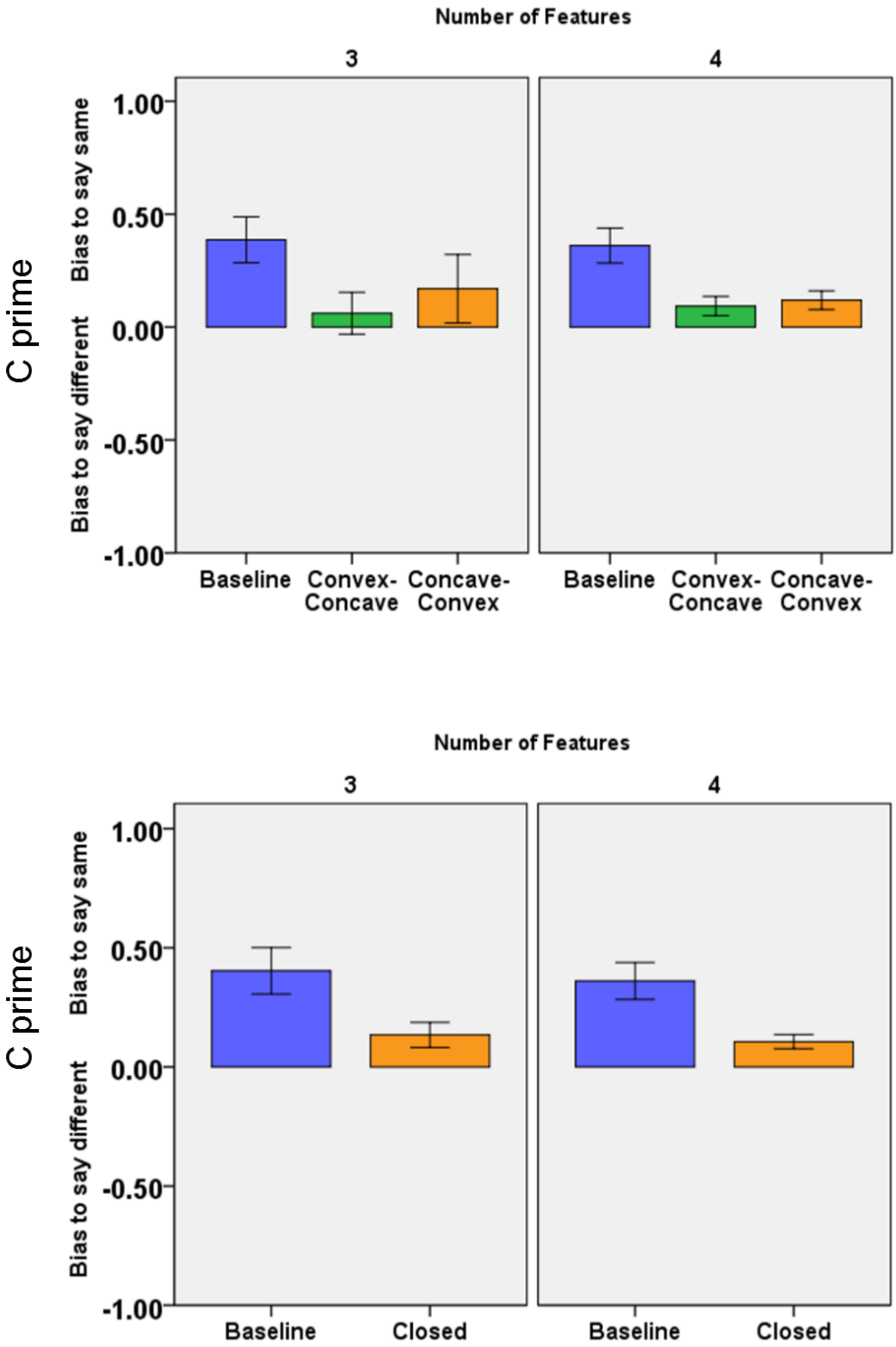


Figure 3.7. Response Bias for baseline, convex and concave (top row) and mean bias (c prime) for baseline and closed condition (bottom row) includes both convex and concave stimuli. Error bars are ± 1 SEM.

3.3.3 Results

Our first ANOVA tested the difference between changes from convex in the first interval to concave in the second interval and changes from concave in the first interval to convex in the second interval. In the mixed design we included convexity (from convex and from concave) as a within-subjects factor and position (left or right) as between-subjects factors. We found a significant difference from changes from convex in the first interval to concave in the second interval (F (1,36) = 5.69, p = 0.02, partial η^2 = 0.13) and no other significant effects (F (1,36) = 4.08, p = 0.05).

In a second analysis we compared the baseline condition in which the contour was not closed with the closed object. The design was the same as the first analysis except that closure (open and closed) replaced convexity. There was a significant effect or interactions between number of parts and position (F (1,36) =5.28, p=0.027, partial η^2 = 0.19) and, more importantly, we found a significant effect of closure (F (1,36) = 4. 46, p = 0. 04, partial η^2 = 0.11) with better performance in the baseline condition.

The same analyses that were performed on d prime were also performed on a measure of bias. We used the standardised c criterion (Macmillan, Creelman, 2005). For the analyses of the two types of changes (from convex to concave and vice versa) there was no significant effect or interaction (F(1,36) = 2.98, p = 0.09). For the analysis of the baseline and the closed conditions we found a significant effect of closure (F (1,36) =16.71, p=0.001, partial η^2 = 0.31). There is a stronger tendency to say "same" in the baseline condition compared to when the convexity changes between intervals.

3.3.4 Discussion

In Experiment 4 we aimed to test changed between the two intervals in either condition (convex-concave or vice versa). This should be replicated as in Experiment 3 if closure is the reason for the relatively poor performance at baseline. Performance should be improved in the baseline condition (in which coding changes) compared to the new conditions, if coding ambiguity is an influential factor. This is supported by the results. The increase in performance in the baseline condition compares to the closed condition. This can be attributed to the fact that the change between convex and concave is difficult; this change may be responsible for the worsened performance in the closed condition. Because of the mixed results between Experiment 3 and Experiment 4 (In Experiment 3 we found that detection of changes to convex or concave features did not differ but detection of changes to features that were either convex or concave was better than detection of changes to the baseline open contour) we will conduct further studies.

3.4 Experiment 5 (Change in convexities and concavities versus no change)

Method

The purpose of this experiment was to try and explain the difference in performance relative to the baseline condition in Experiment 3 and Experiment 4; we will conduct another experiment to focus on the within-subjects effect and excluded between subjects effects because of the large number of subjects.

This experiment is a combination of Experiment 3 and Experiment 4. In half of the trials, the closure changed from left to right or right to left, and in the other half the closure did not change. In the control experiment we prefer to use 4 features only to prevent an excessively high number of trials.

3.4.1 Participants

Twenty members of the University of Liverpool community took part in the study (12 females were involved, mean age 20 years).

3.4.2 Stimuli, Design, and procedure

The same procedure as Experiment 5 was used. We have five conditions in this case: Convex condition, concave condition, baseline condition, and change from convex to concave, and change from concave to convex. Half of the participants have the features presented on the left and change condition and half of the participants have the features presented on the right without any change.

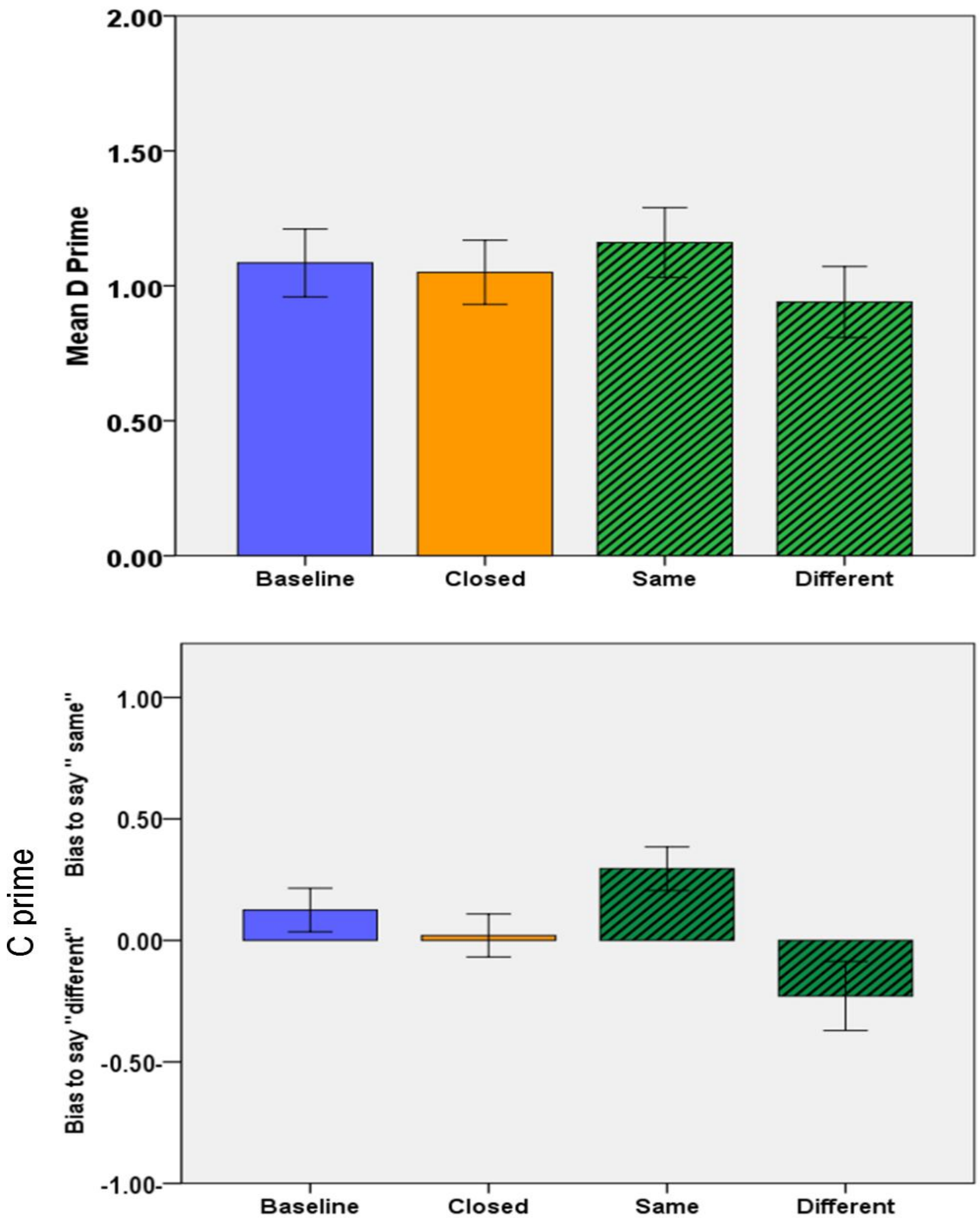


Figure 3.8. Results from Experiment 5. Sensitivity d prime and response Bias for baseline, closed, same, and different (top row) and mean bias (c prime) for baseline and closed, same, and different (bottom row) includes both convex and concave stimuli. Error bars are ± 1 SEM.

3.4.3 Results

A mixed ANOVA on d prime included condition (baseline, same, and different) as a within-subjects factor and position (left or right) as a between-subjects factor. There was a significant main effect of condition (F (1,36) =3.71, p=0.034, partial η^2 = 0.17).

In a second analysis we compared the closure (open or closed) condition in which the contour was change or not. There was a significant effects or interactions of type of closure condition in which the contour was change (different) or not change (same) (F (1,18) =7.86, p=0.012, partial η^2 = 0.30).

The same analysis that was performed on d prime was also performed on a measure of bias. We used the standardised c criterion. There was a significant effect of type of closure (F (1,18) =7.86, p=0.012, partial η^2 =0.30). For the analyses of the closure (open and closed) there was no significant effect or interaction (F (1,36) = 2.98, p = 0.09).

We found a significant effect of type of closure (F (1,36) =16.71, p=0.001, partial η^2 =0.31). There is a stronger tendency to say "same" in the condition that convexity did not change to concavity or vice versa compared to when the convexity changes to concavity or vice versa between intervals.

In this experiment, we used a mixed design from Experiment 3 and 4 and included five conditions; convex condition, concave condition, baseline condition, change from convex to concave, and change from concave to change. It was found that performance improved in closed condition relative to baseline condition. Moreover, performance improved in closed condition that did not change relative to the closed condition that did change. Therefore, it is arguable that convexity and concavity are important aspects of shape analysis and representation, but there is no basic difference in how convexities and concavities are processed. Experiment 5 will supplement Experiment 4, to improve our understanding of the improved performance in the baseline condition and the worsened performance when the closure changed between convex and concave (or vice versa) in Experiment 4. Thus, observers used the closed features as parts and the improved performance in the convex and concave condition did not change. This helps to store information in visual short-term memory, although there is no basic difference between convexity and concavity coding.

3. 5 General discussion

There is controversy in the literature regarding the evidence for a difference in chance detection performance between convexity and concavity. This is because several perceptual tasks are sensitive to convexity or concavity coding, presumably because this type of coding plays a fundamental role in part parsing (Bertamini, 2001; Hulleman et al., 2000). Furthermore, Barenholtz et al., (2003) and subsequently Cohen et al., (2005) have argued that detection performance for changes in concavities is higher compared to changes in convexities. However, such changes may be driven by the different context in which convex and concave changes are produced (Bertamini, 2008).

For the first time, we directly compare convex and concave segments of a contour in a standard VSTM task. Aforementioned psychological and neuroscience studies have generally found that the capacity of VSTM is limited to three or four items (Baddeley,1986; Logie et al.,1990; Alvarez & Cavanagh, 2004; Cowan, 2001; Jiang, Olson, & Chung, 2000; Luck & Vogel, 1997; Pashler, 1988; Logie, 1989; Lee & Chun , 2001; Olson & Jiang, 2004; Olsson & Poom ,2005; Eng et al., 2005; Awh, Barton, & Vogel ,2007; Vogel et al., 2006; Makovski & Jiang ,2000; Rouder et al., 2008; Luck & Hollingworth, 2008; Alvarez & Cavanagh, 2008). Focussing on this limitation, our study compared convex and concave segments of a contour in a standard VSTM task. It is possible that having to perform the task at the limit of the short-term memory capacity would reveal a difference in participant performance that may not be present for tasks with fewer features and shorter retention intervals.

As previously mentioned, there is contrasting opinion and evidence on differential levels of performance for convexity and concavity. For example, an advantage for detection of concavity on a detection task has been reported (Barenholtz, Cohen, Feldman, &Singh, 2003). However, when other factors are removed, no such advantage is found (Bertamini, 2008; Bell, Hancock, Kingdom, & Peirce, 2010). Despite this, a recent fMRI adaption study has found privileged coding of convexity, and therefore higher sensitivity in LOC (Haushofer, Baker, Livingstone, & Kanwisher, 2008). There is also experimental evidence for the greater importance of convexities in a symmetry detection task with respect to concavities (Hulleman &Olivers, 2007).

Furthermore, Bertamini (2001) has reported a convexity advantage in a task in which participants were faster at judging the position of convex stimuli than concave vertices. He speculated that this was due to the fact that convex vertices define parts of solid objects, and parts are perceived as having a position (Bertamini, 2001). On the other hand, concave vertices are perceived as boundaries between parts. So, positional information is more directly involved with convex regions.

As we mentioned earlier, one study has investigated the role of convex regions in VSTM. Sakai and Inui (2002) have shown that the limitation in capacity of VSTM applies to convex parts (i.e. convex segments of a closed contour). Furthermore, retention of visual information became more easily when the curvature of the contour belongs to convex regions and that retention of information applies to four convex segments (Sakai & Inui, 2002).

There have also been reports of a concavity advantage in change detection (Barenholtz et al., 2003). It has been proposed that concavity plays a more important role than convexity in shape perception. Concave vertices can be easily detected in visual displays. For instance, the search for a concave target among convex stimuli is more efficient and accurate than the search for a convex target among concave stimuli (Hulleman et al., 2000; Humphreys & Muller, 2000; Wolfe & Bennett, 1997; Bhatt et al., 2006). However, this may have been a consequence of a change in perceived part structure. All subjects were tested in a change detection task because this technique is the most widespread task used in the behavioural studies of VSTM (Vogel & Luck, 1997).

There are cognitive models of shape analysis and representation that utilize convexity and concavity information without assigning priority to one of them (Bell, Gheorghiu, & Kingdom, 2009). Drawing on data from studies of adaptation, no difference between convexity and concavity has been noticed (Bell et al., 2010). However, a recent fMRI study has found an advantage for processing convexity over concavity in the anterior lateral occipital complex (LOC). Meanwhile, no behavioural differences on a change detection task have been found (Haushofer et al., 2008).

On the other hand, Elder and Zucker (1993) provide ample evidence that closure may facilitate shape processing including detection of change (Luck & Vogel, 1997; Luck, Vogel, & Woodman, 2001; Mathes, & Fahle, 2007). If this is the case, closed regions should be associated with better performance compared to a contour in isolation (not closed). This has been included as a baseline condition in our experiments. In Experiment 3, it was found that change detection was better for closed objects compared to the baseline. It is possible that closure has acted to create parts that were easier to store in visual short-memory. However, closure might have simply allowed attention to remain constrained to a smaller region. There was no overall difference between convexity and concavity in detecting the change in VSTM and this cannot be easily interpreted. However, closed contour has significantly contributed into the baseline condition.

Our results showed no difference between positive curvature (convex regions) and negative curvature (concave regions). The closure of the contour reported in this set of experiments can also be compared with another finding by Elder and Zucker (1993), who confirmed a positive closure of the contour component in facilitating shape processing and computed the shapes very rapidly and efficiently relative to the ambiguous stimulus. Similarly, Kovacs and Julesz (1993) have found that participant's performance declined when the features were isolated, but performance improved when the features were inside a closed contour. Participants were asked to detect a target inside a closed contour and outside non-closed contour (baseline condition) and it was concluded that closed contour is a key factor facilitating shape processing. Consistent with other psychophysical studies, it has been found that closed contour detecting occurs more easily relative to baseline condition (non- closed contour).

In Experiment 4, the participants were required to detect the change from first interval to second interval. Therefore, they saw concave features in the first intervals but had to judge the change after seeing convex features in the second interval (or vice versa). This advantage in Experiment 3 could be due to one of two factors: (a) object advantage; where attention may be constrained to the surface of the object when this is present but it may spread to the whole screen when the contour is not closed and (b) coding ambiguity; where the baseline has segments that may be perceived as either convex or concave and this coding may also change between presentations. Experiment 4 was designed to test these factors. Coding was always changing between the two intervals in the convex→concave or concave→convex conditions. If closure is the reason for the poorer performance at baseline in Experiment 3, this should be the case again in Experiment 4. Conversely, if coding ambiguity is important, performance should be better in the baseline compared to the new conditions in which coding always changes. The last hypothesis proved that the closure advantage disappeared if the region changed from the left to the right side between intervals. Thus, convexities turn into concavities and vice versa. In this case, another control experiment is required to explain the mixed results from Experiment 3 and 4. However, in this experiment, we used a mixed design from Experiment 3 and 4 and included five conditions; convex condition, concave condition, baseline condition, change from convex to concave, and change from concave to change. It was found that performance improved in closed condition relative to baseline condition. Moreover, performance improved in closed condition that did not change relative to the closed condition that did change. Therefore, it is arguable that convexity and concavity are important aspects of shape analysis and representation, but there is no basic difference in how convexities and concavities are processed. It therefore seems that the convexity and concavity advantages reported are due to the demands of the specific tasks used in the experiments rather than any intrinsic differences between the perception of convexities and concavities. If convexities and concavities (closed condition) play a critical role in visual short-term memory we need to relate this to how the question of sensitivity to convexities and concavities in bilateral symmetry in a two-interval (Experiment 6) and a single-interval (Experiment 7) detection task. Consequently, in the third set of studies we tested whether any convexity advantage is specific to bilateral symmetry.

CHAPTER 4| The role of convexity in the perception of symmetry

This chapter is adapted from Bertamini, M. Helmy, M.S., & Hulleman, J. (submitted). The role of convexity in perception of symmetry and in visual short-term memory. DOI:

Abstract:

Background

This study used repeated shapes as well as reflected shapes, to test whether the convexity advantage previously outlined is specific to reflection (bilateral symmetry). A recent study reported that deviations from symmetry carried by convexities were easier to detect than deviations carried by concavities (Hulleman & Olivers, 2007). We extended this work from a detection of reflection of a contour (i.e. bilateral symmetry), to a detection of repetition of a contour (i.e. translational symmetry). We will introduce a definition for bilateral symmetry (reflection) and translation (repetition) from the outset of this chapter. Bilateral symmetry occurs when all the elements in one side of the axis of symmetry appear in the reflected position on the opposite side, as in the letters (b d). In contrast, translation (repetition) refers to a pattern produced by shifting each element by a fixed distance and common direction, as in the letters (b b); in other words, a repeating pattern.

Methods

Participants were drawn from the student population of the University of Liverpool, either voluntarily or in return for course credit. In the course of the study, participants were asked to decide whether a symmetrical shape appears in the first interval or in the second interval (Experiment 6a). In Experiment 6b, the task was to compare two objects and decide whether they were the same or different. Experiments 7a and 7b replicated the previous experiments, but using one interval rather than two. Experiment 8 compared convex and concave shapes as separate tasks.

Results

These experiments have successfully demonstrated that there are convexity advantages (when compared to concavities) in a task requiring the comparison of two similar objects. No significant effect for bilateral symmetry was found (Experiment 6a and 7a), and the effect was only present when comparing features of translated objects (Experiment 6b and 7b). Consequently, when comparing convex and concave regions as separate tasks, results indicate no significant sign of convexity (Experiment 8).

Discussion

The results of this study support the hypothesis that convex visual regions play a crucial role in detection of regularity, although not in bilateral symmetry (reflection). However, any sign of a convexity advantage disappeared when participants did not need to choose which region (concave or convex) to monitor.

4.1 Introduction:

Detection of symmetry is one of the most salient features of objects, and is therefore an interesting topic of study. Symmetry is important in various scientific disciplines including social science, mathematics, physics and philosophy of science. Symmetry is also an observable feature of the natural world, and of artistic works spanning all world cultures (Palmer & Hemenway, 1978). Symmetry is a prominent visual characteristic easily recognised by the human visual system, which has the ability to coherently identify bilateral symmetry presented through visual input. Human investigation has found symmetry throughout a huge variety of fields, from the microcosm of string theory, through to the structure of crystals, or the huge architecture of galaxies (Palmer & Hemenway, 1978; Tyler, 1995; van der Helm & Leeuwenberg, 1996).

Symmetry is one of the most basic aspects of visual input and therefore of visual perception, both in visual human systems and in various other species (Barlow & Reeves, 1979; Giurfa, Eichmann, & Menzel, 1996; Horridge, 1996). For this reason, it is widely held that the recognition of symmetry is a fundamental part of the perceptual process (van der Helm, 2010). Symmetry recognition is closely related to the recognition of shape, and similar shapes can be described differently when fixed in a context of horizontal or vertical symmetry (Cardaci et al., 2009). When we recognise elements as symmetrical to each other, we pay attention and integrate them to a coherent single percept. Furthermore, symmetrical images are, in general, perceived as "figure", not as "ground" in the visual figure/ground separation process (Kansiza & Gerbino, 1976).

In 1971, Julesz first discussed the significance of the area around the axis of symmetry, and discovered the perceptual importance of information within a small strip around the symmetry axis. In his studies, this axial area was determined by a random dot texture that could be recognised either as symmetrical or not symmetrical, without reference to the characteristics of areas farther away from the axis. However, Wagemans (1995) observed that the axial strip seems to be a necessary element in contributing the perception of symmetry in 2-D shapes (rather than dot patterns) when considering areas farther away from the axis of symmetry. For example, in Palmer and Hemenway's study (1978), participants were easily able to identify the symmetry presented in the outline shapes where the internal characteristics close to the axis of symmetry did not display symmetrical properties (Palmer & Hemenway, 1978).

Before introducing the study on which this chapter focuses, I must briefly discuss some definitions: namely, a specific definition for bilateral symmetry (reflection), and translation (repetition). Bilateral symmetry occurs when all the elements in one side of the axis appear in the reflected position on the opposite side, as in the letters (b d). In contrast, translation (repetition) refers to a pattern produced by shifting each element by fixed distance and common direction, as in the letters (b b); in other words, a repeating pattern.

The importance of symmetry is common to Gestalt approaches, computational approaches, and neuropsychological studies. Research results indicate that participants tend to interpret symmetrical shapes as figures, and non-symmetrical shapes as background (Baylis & Driver, 1994; Cardaci et al., 2009; Machilsen, Pauwels, & Wageman, 2009). This forms part of a wider context, in which researchers have reported that some key factors (symmetry, similarity, proximity, and closure) enable participants to detect and organize objects in the visual environment (Machilsen et al., 2009).

Many of the Gestalt scholars have emphasized the significance of bilateral symmetry. For example, in 1960 Michaels highlighted the importance of symmetry in determining subjective judgments of geometrics, regularity, and familiarity using a large group of systematic distortions of a square. Freyd and Tversky (1984) also attributed symmetry with a key significance in the recognition of shape, suggesting that symmetry helps in establishing an “object-centred coordinate frame”. Similarly, Howard and Templeton (1966) argued that symmetry is a salient property of objects, and furthermore that the axis of symmetry always defines the suitable orientation of objects (Freyd & Tversky, 1984).

The ability to detect symmetrical objects is important because various natural (and manufactured) objects are either symmetrical or almost symmetrical in the world around us. More specifically, most of these symmetrical objects tend to occur as (bilaterally) symmetrical (Sawada & Pizlo, 2008). In 1889, Mach discovered the relative ease with which the human visual system can recognise bilateral or mirror symmetry in comparison with other types of symmetry such as translation or rotation symmetry, uncovering an interesting facet of human perception (Koning & van Lier, 2006; Tyler, 1995).

Symmetry is a vital component of visual perception and shape recognition, helping us to organize and recognize different types of objects in our environment. Many authors have proposed that symmetry plays an important role in human perception (for example, Barlow & Reeves, 1979; Baylis & Driver, 1994, 1995; Dakin & Watt 1994; Wagemans, 1995, 1997; Bertamini, Friednberg, & Kubovy, 1997; Huang, Pashler, & Junge, 2004; Csatho, van der Vloed, & van der Helm, 2005; Hulleman & Oliver, 2007; Machilsen et al., 2009; Koning & Wageman, 2009; Cattaneo et al., 2010).

We will now explore in more depth a recently discovered convexity advantage. A recent study by Hulleman and Olivers (2007) reported that deviations from symmetry carried by convexities were easier to detect than deviations carried by concavities. Study participants were asked to judge which of a pair of stimuli had perfect bilateral symmetry; the foil stimulus was similar to the symmetrical stimulus, but deviated from perfect symmetry either on convex or concave regions. The study found that it is easier to detect asymmetry when there is a mismatch between the convexities on either side of the symmetry axis, leading the authors to conclude that concavities are less important than convexities in symmetry perception. Hulleman and Olivers further suggest that the actual shape of concavities is less important in symmetry perception, because the main role of concavities is to act as part boundaries in the representation of the shape of objects. In other words, participants detected targets more easily in convex than concave regions, irrespective of their position relative to the axis of symmetry (Hulleman & Olivers, 2007).

This study aims to address the following research question: whether the effect found by Hulleman and Olivers (2007), as outlined above, is specific to the perception of bilateral symmetry, or whether it applies more generally to other types of visual pattern. This study sought to extend the work of Hulleman and Olivers by presenting shapes that were repeated rather than reflected, in order to test whether the convexity advantage was specific to bilateral symmetry. To this end, a similar task was used in a separate experiment (Experiment 7) in which there was a repetition of two objects instead of a pair of symmetric objects.

4.1.1 Detection of symmetry: reflection vs. translation

A number of studies have examined the detection of reflectional symmetry (Tyler, 1995; van der Helm & Leeuwenberg, 1996; Wagemans, 1995, 1997; Koning &

Lier van R, 2006; Cattaneo et al., 2010; Csatho’, van der Vloed & van der Helm, 2003). However, less attention has been paid to the detection of repetition (Baylis & Driver, 1994, 2001; Bertamini et al., 1997).

A number of authors (Baylis & Driver, 2001; Wageman, 1995; Bertamini et al., 1997) have pointed out that most studies of symmetry focus on reflection. They concluded that symmetry detection is easier than detection of repetition for two reasons; firstly, because the detection of symmetry requires the use of two cues or properties (translation and reflection), whereas the detection of repetition only includes translation; and secondly, because symmetry detection involves only one object, whereas symmetry repetition involves multiple objects and may therefore have a memory cost (Baylis & Driver, 1994, 1995; Bertamini, Friedenberg, & Kubovy, 1997; Friedenberg & Bertamini, 2000; Machilsen, Pauwels, & Wageman, 2009; Koning & Wageman, 2009; Bertamini, 2010). So in summary, some types of visual regularity, such as mirror symmetry, appear easier to detect than others (Wagemans, 1997).

Numerous researchers (Corballis & Roldan, 1974; Baylis & Driver, 1995; Bertamini et al., 1997; Koning & Wageman, 2009; van der Helm & Treder, 2009; Bertamini, 2010) have found an interaction between the number of objects observed and the type of symmetry detected, suggesting that symmetry is easier to detect when the stimulus contours (outline) belong to one object rather than two objects, whereas repetition is easier to detect when the stimulus contours belong to two objects rather than one.

The above studies provide evidence that symmetry detection is easier than the detection of repetition in a single object when using matching strategies, such as lock-and-key and gap matching (Bertamini et al. 1997), or jigsaw matching (Baylis & Driver, 1995) to detect pattern. For example, Bertamini, Friedenberg, and Kubovy (1997) explored reflection and translation in their study, using one object in a first test and then two objects in a second, where in both instances participants were asked to respond as quickly as possible to decide whether the contours were the same or different in both condition reflection and translation. The authors concluded that participants are quicker to identify the reflection symmetry in a single object, but conversely quicker to identify translation symmetry in two objects (Bertamini et al., 1997).

Although there is agreement regarding the key role of matching strategies in the perception of symmetry detection, it is nonetheless important to note that some researchers contend that structural coding, rather than matching strategy, is responsible for detection of regularity (Baylis & Driver, 1995; Bertamini et al., 1997; Bertamini, Friedenberg, & Argyle, 2002; Koning & Wageman, 2009; van der Helm & Treder, 2009).

In another study, Corballis and Roland (1974) used dot patterns to measure the difference between perception of symmetrical and non-symmetrical regularity. In this task, participants were asked to decide whether the dots they saw on a screen were symmetrical or non-symmetrical. The researchers concluded that detection of regularity was faster when the dots were close to each other, and slower when they were more widely spaced (Corballis & Roland, 1974). This is consistent with the observations of Bertamini (2010), who, using stereograms, demonstrated that participants are able to recognise regularity more rapidly when the contour belongs to a single object (reflection), with the opposite being true for translations (Bertamini, 2010). In his task he asked participants to respond as soon as translation and reflection appeared regular in an on-screen dot pattern, and to give an alternative response when the regularity disappeared.

Various studies have analysed symmetry detection; for example, Baylis and Driver (1994, 1995), and Wagemans (1995, 1997) asserted that symmetry can be perceived quickly, efficiently, and in parallel with other perceptual processes, whereas repetition can only be perceived by means of a serial process (Baylis & Driver, 1994, 1995; Wagemans, 1995; Machilsen, Pauwels, & Wageman, 2009). This is consistent with various studies in which the detection of symmetry is very rapid (e.g. Julesz, 1971;; Barlow & Reeves, 1979); generally, participants needed between 50 msec and 100 msec to detect symmetry and distinguish between symmetrical and non-symmetrical shapes (Machilsen et al., 2009).

Another aspect of symmetry detection that has received attention is the orientation of shapes. Numerous researchers have argued that vertical symmetry is easier to detect in the visual system than horizontal symmetry. For example, Corballis and Roldan (1974), Julesz (1971), Barlow and Reeves (1979), Palmer and Hemenway (1978), Baylis and Driver (1994), Wagemans (1997), and Koning and van Lier (2006) suggested that participants find it is easier to detect vertical asymmetry than horizontal asymmetry, as in test conditions participants were faster and more accurate at judging the position of vertical symmetry than horizontal symmetry (Baylis & Driver, 1994; Cardaci et al., 2009; Friedenberg & Bertamini, 2000; Hulleman & Humphreys, 2004; Machilsen et al. , 2009).

Moreover, various studies have highlighted the importance of vertical symmetry within symmetry detection; for example, Barlow and Reeves (1979), Masame (1984), Palmer and Hemenway (1978), Royer (1981), Wagemans, Van Gool, and d'Ydewalle (1992), Wenderoth (1994), and Cattaneo et al., (2010) all concluded that there is a continuous perceptual process involved in detecting symmetry, including vertical, horizontal, and oblique orientation; participants are faster in detecting vertical than horizontal orientation, and detect oblique orientation slowest of all. This finding is consistent with Friedenberg and Bertamini's study (2000) investigating the role of vertical symmetry in detection of pattern, and with other studies investigating the effect of differentially sized tops and bottoms of shapes during symmetry perception. Hulleman and Humphreys (2004) illustrated that participants were faster and more accurate at judging symmetry of shape stimuli featuring a wide base and a narrow top than an oppositely shaped object.

4.1.2 The role of contour polarity

Contour polarity refers to the sign of a contour's curvature. By convention, negative curvature is concave and positive curvature is convex. The term "contour polarity" is thus used to highlight the presence of convexities and concavities, and should not be confused with contrast polarity.

A number of researchers (Bertamini et al., 1997; Baylis & Driver, 2001; Hulleman & Oliver, 2007) have suggested that objectness (figure or background) plays a central role in the perception of symmetry. For example, Bertamini et al, (1997) claimed that reflection plays a fundamental role in distinguishing objects (figures) from background (field). Experimental participants have better recognition performance when contours belong to a single object (in the reflection symmetry). On the other hand, participants have better performance when the contours belong to different objects (in the translation symmetry) because of a strategy named a lock-and-key process. A possible explanation for this is that visual attention moves more easily within objects than between objects, and recognition performance is therefore faster when objects belong to the same units or objects than to different units or objects (Bertamini et al., 1997; Bertamini, et al., 2002).

Another key piece of evidence comes from a series of experiments conducted by Baylis and Driver (2001), which demonstrated that participants' performance was improved when symmetry perception was applied to a single object rather than multiple objects. In symmetry detection, each side of the contour is an identical mirror-image of the other; for example, a concave region along one side relates to a similarly concave along the other side of the shape or object, whereas, in symmetry repetition, the two sides of the contour are mismatched (i.e. a concave region along one side corresponds to a convex contour along the other side of the object). As a result, detection of symmetry becomes harder when the contours are repetitions rather than reflections (Baylis & Driver, 2001). This is consistent with the findings of Kansiza and Gerbino (1976), who showed that symmetry detection, was easier for participants when they perceived a convex contour as a figure, and their responses were accurate with reference to the figure perceived as convex. For example, in Kansiza and Gerbino's study, 73 out of 80 participants perceived the convex areas (symmetrical stimulus) as a figure (Kansiza & Gerbino, 1976). Moreover, there is much evidence from a wide body of research literature to support the important role of contour curvature in the perception of part structure.

Bertamini (2001) found that participants were faster at judging the position of convex rather than concave stimuli vertices. He demonstrated that this result was due to the perception of convex vertices defining parts of solid objects, whereas concave vertices conversely tend to be perceived as boundaries between parts. This means that perception of positional information is more directly involved with convex regions than with concave regions.

In Bertamini's experiment, the central region of the contour was divided into red (the figure) and green (the background); the stimulus was positioned in either the top half or bottoms half of the figure, and participants were required to judge the position of a vertex with respect to a base line. The results confirmed that it is easier to judge the position of a convex vertex than the position of a concave vertex (Bertamini, 2001).

Hulleman and Olivers (2007) have shown that it is easier to detect symmetry when a contour belongs to a convex region than when a contour belongs to a concave region. In other words, they found that convex vertices play a role in determining the structure of an object. Therefore, concave vertices play a role in determining how the shape of an object is perceived. In their research, Hulleman and Olivers established under which conditions it is easy or difficult to recognize shapes as symmetrical or asymmetrical. Their study used either an actual physical object (convexity or concavity) or a small dot as a stimulus. This will help to make a balance between stimulus near or faraway from the central of the axis. This is the case even when convexities are situated away from the axis of symmetry alignment and concavities are, conversely, close to the alignment of symmetry (Hulleman & Olivers, 2007). Hulleman and Olivers found that the relative contribution of convexities and concavities in symmetry perception depended on their relative roles in the shape perception, and moreover the symmetry of convexities can be more simply determined than the symmetry of concavities. This supported the idea that symmetry perception in 2D shapes is mainly governed by shape perception. The normal bias towards the axis found in symmetry perception.

In contrast, other researchers (Barenholtz et al., 2003; Cohen et al., 2005) have proposed that concavity plays a more important role than convexity in shape perception. Concave vertices can be easily detected in visual displays (Hulleman & Olivers, 2007); for instance, the search for a concave target among convex stimuli is more efficient and accurate than the search for a convex target among concave stimuli (Hulleman et al., 2000; Humphreys & Muller, 2000; Wolfe & Bennett, 1997; Bhatt et al., 2006).

Overall, we can conclude that the closure of a contour (forming a convex region and a concave region) plays a crucial role in shape perception. It seems that there is an interaction between the type of symmetry and the type of displays (closed or open). Symmetry is easier to detect when the stimulus contours (outline) belong to one object rather than two objects, whereas repetition is easier to detect when the stimulus contours belong to two objects rather than one. It is therefore easier to detect asymmetry when there is a mismatch between the convexities on either side of the symmetry axis, which leads to the conclusion that concavities are less important than convexities in symmetry perception.

This finding suggested an important question: does the mixed role of convex and concave regions in shape perception imply similarly different roles in the perception of symmetry? More specifically, this question addresses whether participants have a tendency to monitor convexities, and whether this strategy was the reason for the convexity advantage. In order to find out, a series of experiments were conducted in the course of the present study to test this hypothesis.

This study will present examples of the stimuli that Hulleman and Olivers (2007) used in their experiments. Sometimes a closed object (similar to that depicted on the right side of Figure 4.1) was used and sometimes a set of dots (neither a convexity nor a concavity) was used, without any closure (similar to the stimulus depicted on the left side of Figure 4.1).

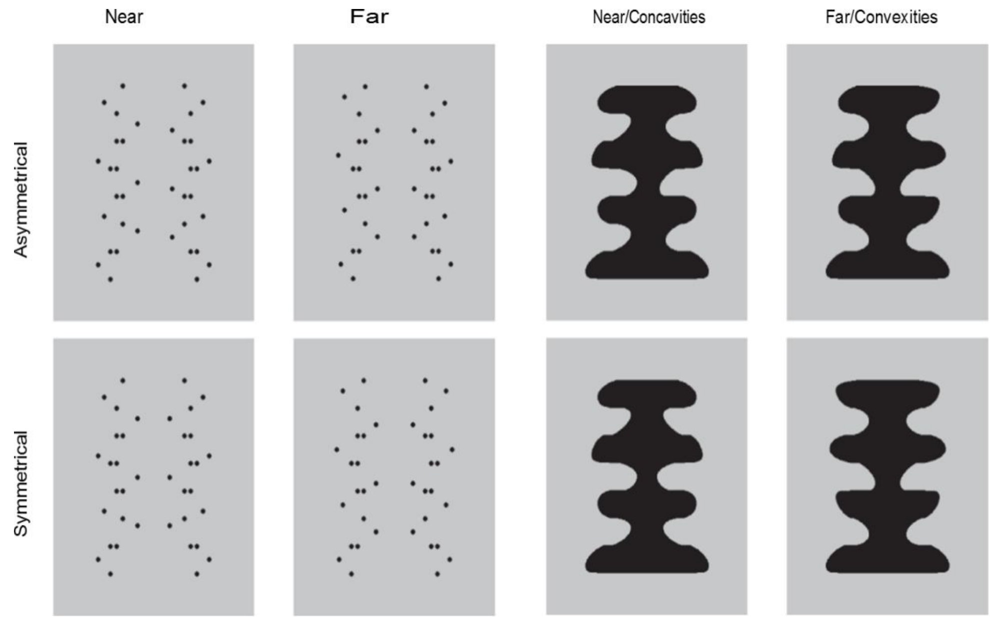
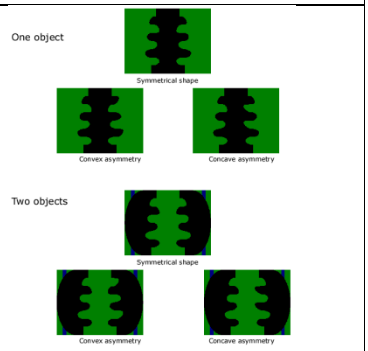
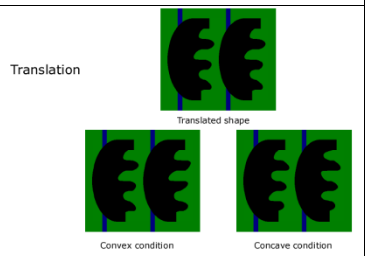


Figure 4.1. Examples of stimuli used by Hulleman and Olivers (2007) in their experiments. In the left side they used symmetrical and asymmetrical dots near or far from axis. On the right side they used Concavities and convexities symmetrical and asymmetrical shapes near or far from axis.

Experiment title	Experiment aim	Stimuli
6(a) Symmetry.	To replicated Hulleman andOlivers (2007) study.	
6(b) Detection of symmetry(Translation)	To test symmetry detection of symmetry for translation, but not for reflection, for a two intervals forced choice task.	

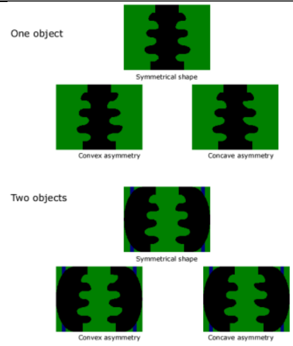
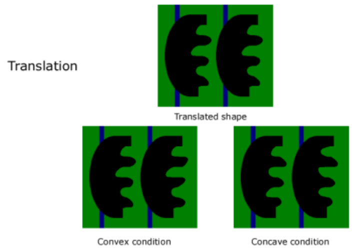
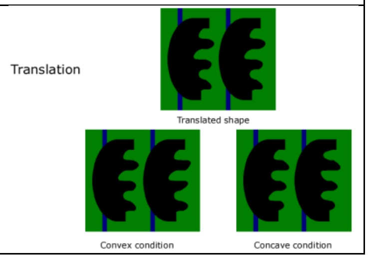
7(a) Symmetry in one interval.	To test the bilateral symmetry in one interval presentation.	
7(b) Detection of symmetry (Translation) in one interval.	To test symmetry detection in one interval presentation.	
(8) Control for Translation (half of trials block convexity) and (half of the trials block concavity).	To control for the translation experiment (how the trials put in separate blocks).	

Table 4.1. Illustrated the symmetry experiments. In Experiment 6a we tried to replicate the findings of Hulleman and Olivers (2007) and In Experiment 6b we test the symmetry detection of symmetry for translation for a two intervals forced choice task. Whereas, In Experiment 7a we test the bilateral symmetry in one interval presentation and in Experiment 7b we test the symmetry detection of symmetry for translation in one interval presentation. In Experiment 8 we comparing convex and concave as separate tasks.

4.2 Experiment 6a (Reflection)

Method

The purpose of Experiment 6 was to examine whether the effect found by Hulleman and Olivers (2007) is specific to perception of bilateral symmetry. Experiment 6a was a replication of the original symmetry experiment, using slightly modified stimuli. Experiment 6b instead used a pair of shapes that were repeated, and in this sense repetition replaced reflection.

When designing the novel experimental protocols, the original stimuli were modified to ensure that the bottom and top of the shape stimuli were identical, in order to avoid the presence of a permanent convexity in the otherwise changing stimuli which inadvertently provided a visual reference for the participants in the original study by Hulleman and Olivers (2007). Given that no equivalent reference existed for concavity, it was deemed preferable to make the comparison between convexity and concavity as balanced as possible in the present study, and this issue was likewise addressed by this modification.

Another minor change with respect to the original study is the fact that two levels of presentation time were used: 100 msec and 450 msec in a factorial design. In other words, both short and long presentations were used for the one object and two object conditions alike. In the original study by Hulleman and Olivers, presentation time was fixed in order to simply compare performance levels. The prediction for the current study was that the difference in performance would be small given that, as in the original study, a mask was not included after the presentation of the stimuli.

4.2.1 Participants

Thirty-two members of the University of Liverpool community took part in the study (participants had a mean age of 20 years, and the group comprised 26 women and 8 men). Participants were split into two equal groups; one group was assigned to the 100 msec presentation time, and the other group to the 450 msec presentation time. Participants in one group were tested first using the single object condition, followed by the two objects condition; this protocol order was reversed for each group.

4.2.2 Stimuli

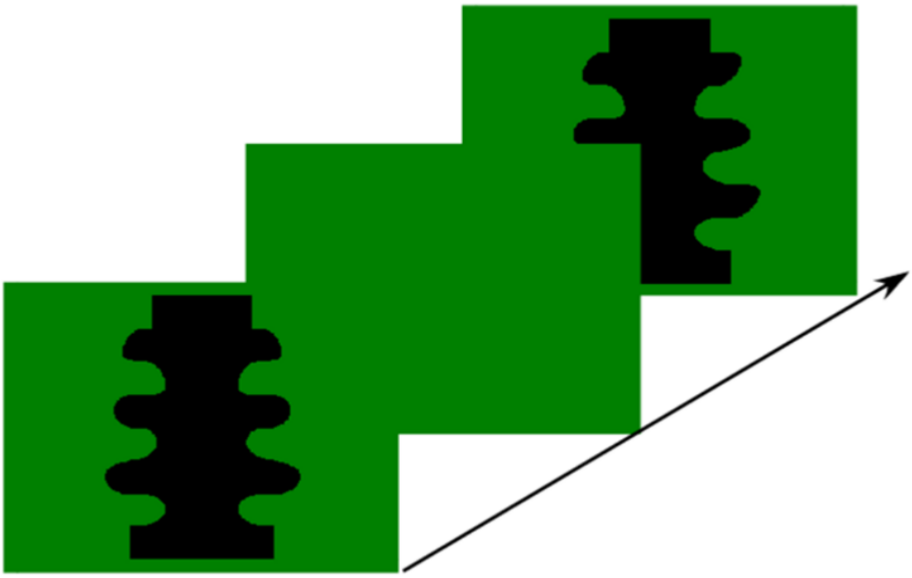


Figure 4.2. In this example a symmetrical shape is shown in the first interval and an asymmetrical shape in the second interval. A trial the first stimulus was presented for 100 msec (450 msec for a different group of observers). After a blank interval of 750 msec, the second stimulus was presented for the same duration.

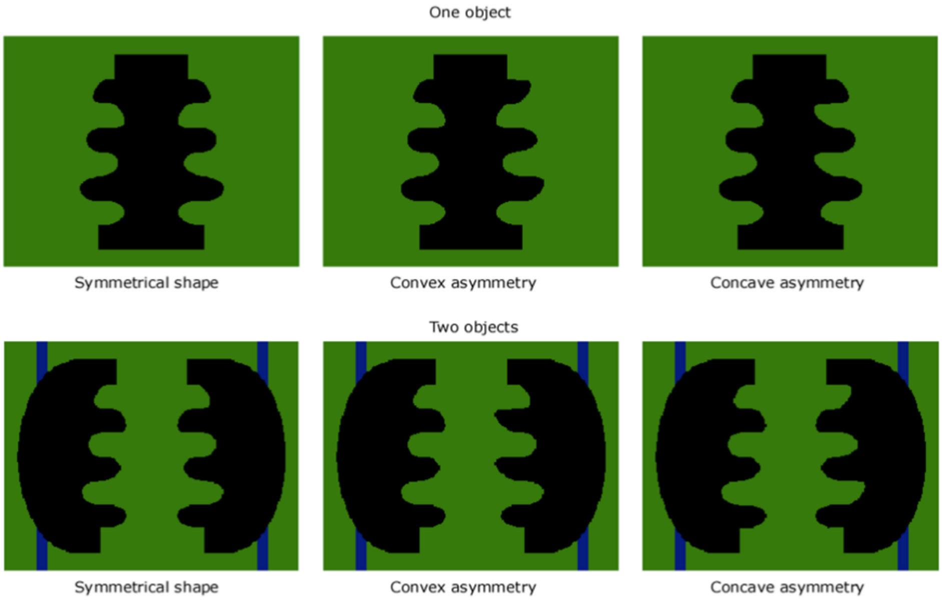


Figure 4.3. Examples of stimuli used in Experiment 6a. Vertical blue bars were part of the background on which the two objects were presented, and were placed to ensure that the black regions were perceived as figures rather than ground.

4.2.3 Design and procedure

Each participant sat in a dimly illuminated room at a distance of approximately 57 cm from the monitor. The participants were shown examples of the stimuli before the experiment started, and were instructed to press the "/ "key or the "z" key to indicate whether the symmetrical shape appeared in the first or second interval. The presentation time (i.e. the length of time for which the stimuli were on the screen) was either 100 or 450 msec. Once the session started, 20 trials formed a practice phase; following this a message appeared asking the participant to start the experiment (by pressing the space bar). The experiment consisted of three blocks of 88 trials; and each participant consequently performed a total 264 trials. The trials were presented in rapid succession, but after the first 88 trials the first block ended and the observer was allowed time to rest. The start of the subsequent blocks was self-paced.

4.2.4 Results

A mixed ANOVA was performed for convexity (convex and concave location) and number (one or two objects) as within- factors, and order (one object first or second) and presentation time (100 and 450 msec) as between- factors. There was a significant effect of number (F (1,28) =11.74, p=0.002, partial η^2 = 0.29) but no other significant effect or interaction between short and long presentation time (all ps >.180). The interaction between convexity (convex and concave location) and order (one object first or second) is not significant (F (1,28) =2.05 *n.s*, p = 0.16). We also performed a signal detection analysis on the data. We report percent correct so as to make the comparison with the original study more direct. An ANOVA with the same design as the one reported above, but using d' as the dependent variable, confirmed the same pattern. Specifically only the effect of number was significant (F (1,28) =8.96, p=0.006, partial η^2 = 0.24).

Therefore, as expected, participants found the task easier with the longer presentation time and when a single object was present as opposed to a pair of objects. The difference in performance between short and long presentation time was small and non significant and, perhaps more surprisingly, no advantage of convexity over concavity could be confirmed. Figure 4.4 shows a (non significant) trend echoing the effect found by Hulleman and Olivers (2007), although in the present study the differences found were much smaller.

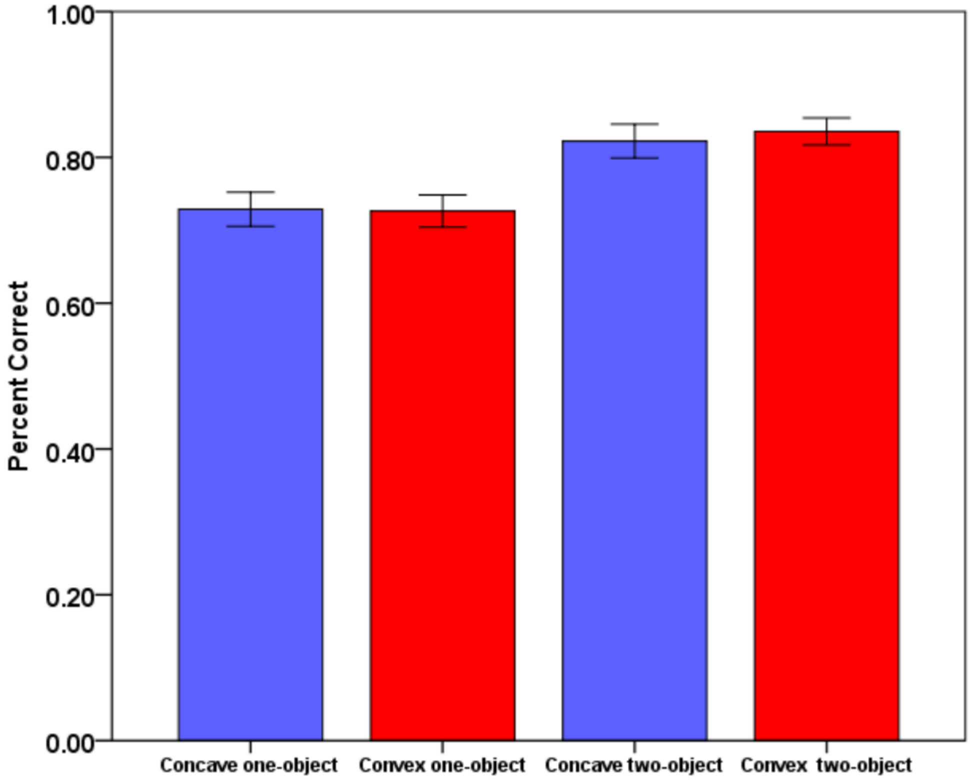


Figure 4.4. The percent correct for convexity and concavity (one object and two objects) for Exp 6a (Bilateral symmetry). Error bars are ± 1 SEM. Blue bars: mismatch in concavities; Red bars: mismatch in convexities.

4.2.5 Discussion

Experiment 6a failed to replicate the convexity advantage reported by Hulleman and Olivers (2007). However, the pattern of results did show a similar trend, and it is therefore possible that a different methodology design may be able to confirm this effect. This may indicate that the participants used a particular strategy (monitoring strategy) when viewing symmetry and asymmetry shapes. The monitor strategy is based on the idea that when a task requires a choice between different shapes, participants focus on one shape and ignore the other. For instance, in this particular experiment the participant needed to decide whether the symmetrical shape appeared in the first or second interval. This is a challenging task and it is difficult to attended on all features if the stimulus. Participants will use the monitoring strategy in such circumstances when the task is challenging, requiring a considered response taking into account all conditions; where a task is less challenging (for example where the required response is based on a single condition only) this strategy is less likely to be used.

4.3 Experiment 6b (Translation)

Method

The purpose of Experiment 6b was to establish whether the effect of convexity advantage is specific of perceiving translational symmetry. Experiment 6b followed the same methodology as the two object condition of Experiment 6a, with the exception that a pair of objects side by side (translation) was used in place of an object reflected around a symmetry axis. A 450 msec presentation time was used throughout, given that no significant performance difference had been detected between the differing presentations times used in Experiment 6a.

4.3.1 Participants

Sixteen members of the University of Liverpool community took part in the study (13 female and 3 male participants, with a mean age 20 years).

4.3.2 Stimuli, design and procedure

Experiment 6b used the same methodology and stimuli as Experiment 6a, with the exception of the switch from reflection to translation, as outlined above.

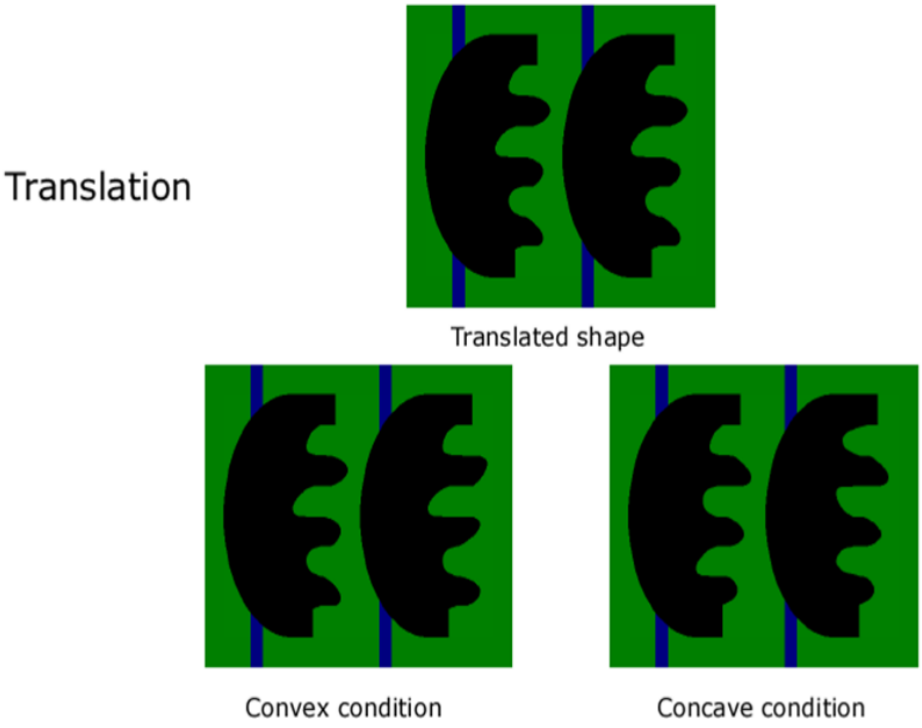


Figure 4.5. The stimulus used in Experiment 6b (a pair of objects is used side by side (translated shape).

4.3.3 Results

The mean percent correct of trials correctly identified by participants is shown in Figure 4.6. The analysis followed the same procedure used in Experiment 6a, with the exception that there was only one factor: convexity. We use the same ANOVA with convexity (convex and concave location) as the factor. The effect was significant (F (1, 15) =7.43, p=0.015, partial η^2= 0.33), with higher performance for the convex condition (see Figure 4.6).

An ANOVA with the same design as the one reported above, but using d' as the dependent variable, confirmed the same pattern. Specifically the effect of convexity was significant (F (1,15) =7.17, p=0.017, partial η^2 = 0.32). This experiment therefore found a result similar to that of Hulleman and Olivers (2007) but using repeated instead of reflected shapes.

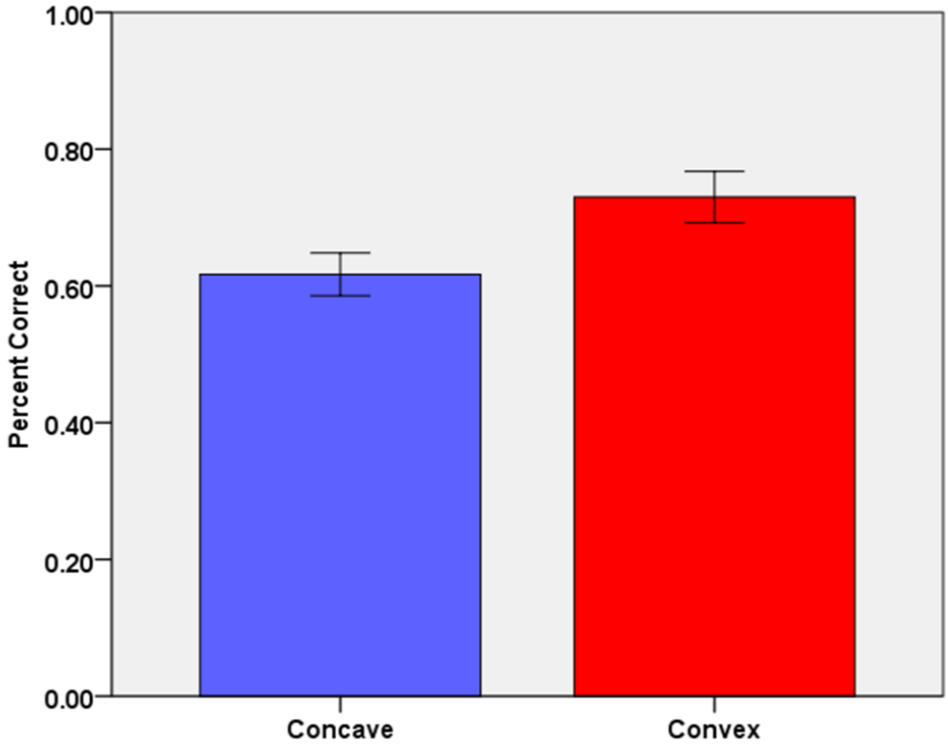


Figure 4.6. The percent correct of convexity and concavity for Exp 6b (Translation). Error bars are ± 1 SEM. Blue bars: mismatch in concavities; Red bars: mismatch in convexities.

4.3.4 Discussion

The main finding from Experiment 6b was that participants found it easier to detect the difference between shapes when there was a mismatch between the convexities, as opposed to the condition where there was a difference between the concavities. This may suggest that participants used a monitoring strategy focusing on the convexities, despite being instructed not to use strategies. This experiment therefore found a result similar to that of Hulleman and Olivers (2007) but using repeated instead of reflected shapes. They interpreted their findings with the knowledge that convex vertices are more detailed and more organized relative to concave vertices (Bertamini, 2008; Bertamini & Lawson, 2008; Rosin, 2000; Pao, Geiger, & Rubin, 1999; Barenholtz, 2010).For example, Kanizsa and Gerbino(1976), propose that symmetry detection is easier, and responses more accurate if participants perceive a convex contour as a figure, and furthermore, vertical symmetry is easier to detect in the visual system than horizontal symmetry. Numerous researchers have associated participant's ease of detection of vertical symmetry compared to detection of horizontal symmetry with faster response times and more accuracy in judging positioning (Wagemans, 1997: Koning & van Lier, 2006; Baylis & Driver, 1994; Cardaci et al., 2009; Friedenberg & Bertamini, 2000; Hulleman & Humphreys, 2004; Machilsen et al., 2009).

4.4 Experiment 7a (Reflection)

Method

The purpose of Experiment 7a was to examine whether the effect found by Hulleman and Olivers (2007) is specific to perception of bilateral symmetry. Experiment 7a presented stimuli in a single interval and asked participants to decide whether the stimulus was symmetrical or not. In Experiment 6 we had used instead a two interval forced-choice task. Results were then analysed on the basis of a signal detection analysis of the data, to measure both sensitivity and bias. As mention in the previous chapter on visual short-term memory the sensitivity measurement is called d prime, and is computed with the formula $d' = z(H) - z(F)$. The sensitivity measure depends on the difference between hits (H) and false alarm (F). The response bias measure is called "c' " (for criterion); this measure depends on the sum of hits and false alarms. The term “response bias” refers to the tendency to favour one possible response and ignore the other. Furthermore, negative and positive bias refer to different responses; the negative bias indicates a tendency to say "Yes", whereas the positive bias indicates a tenancy to say "No" (Macmillan & Creelman, 2005).

4.4.1 Participants

Sixteen members of the University of Liverpool community took part in the study (12 female and 4 male participants, with a mean age 20 years).

4.4.2 Stimuli, design and procedure

Each participant sat in a dimly illuminated room at a distance of approximately 57 cm from the monitor. The participants were given instruction and shown examples of the stimuli before the experiment started. They were instructed to press the "/ "key to indicate a symmetrical stimulus or the "z" to indicate a non-symmetrical stimulus. Presentation time was set at 450 msec. Once the session started, 20 trials formed a practice phase, and after this a message appeared asking the participant to start the experiment (by pressing the space bar). The experiment consisted of three blocks of 88 trials; and each participant consequently performed a total 264 trials. The trials were presented in rapid succession, but after the first 88 trials the first block ended and the observer was allowed time to rest. The start of the subsequent blocks was self-paced.

4.4.3 Results

The mean values for sensitivity and bias are shown in Figure 4.7. A mixed ANOVA was performed with convexity (convex and concave location) and number (one or two objects) as within-participants factors, and order (one object first or second) as a between participant factor. The dependent variable was d prime. There was a significant effect for number (one or two objects) (F (1,14) =12.00, p= 0.004, partial η^2 = 0.46) but no other significant effect (F(1,14) =1.77, p = 0.20) and all (ps > .204).. Therefore, as expected, participants found the task was easier when a single object was present as opposed to a pair of objects. In line with the results of Experiment 6a, there was no advantage of convexity over concavity.

An ANOVA was similarly performed on a measure of bias (the standardized criterion C'). There was a significant effect for number (F (1, 14) =6.48, p=0.023, partial η^2 = 0.32) but no other significant effect (F (1,14) = 3.03, p = 0.10) and all (ps > .103). There was a greater tendency to respond positively to a pair of objects compared to a single object. Figure 4.7 suggests a results pattern in which greater positive bias occurs in conditions where sensitivity is lower. These differences, however, were relatively small.

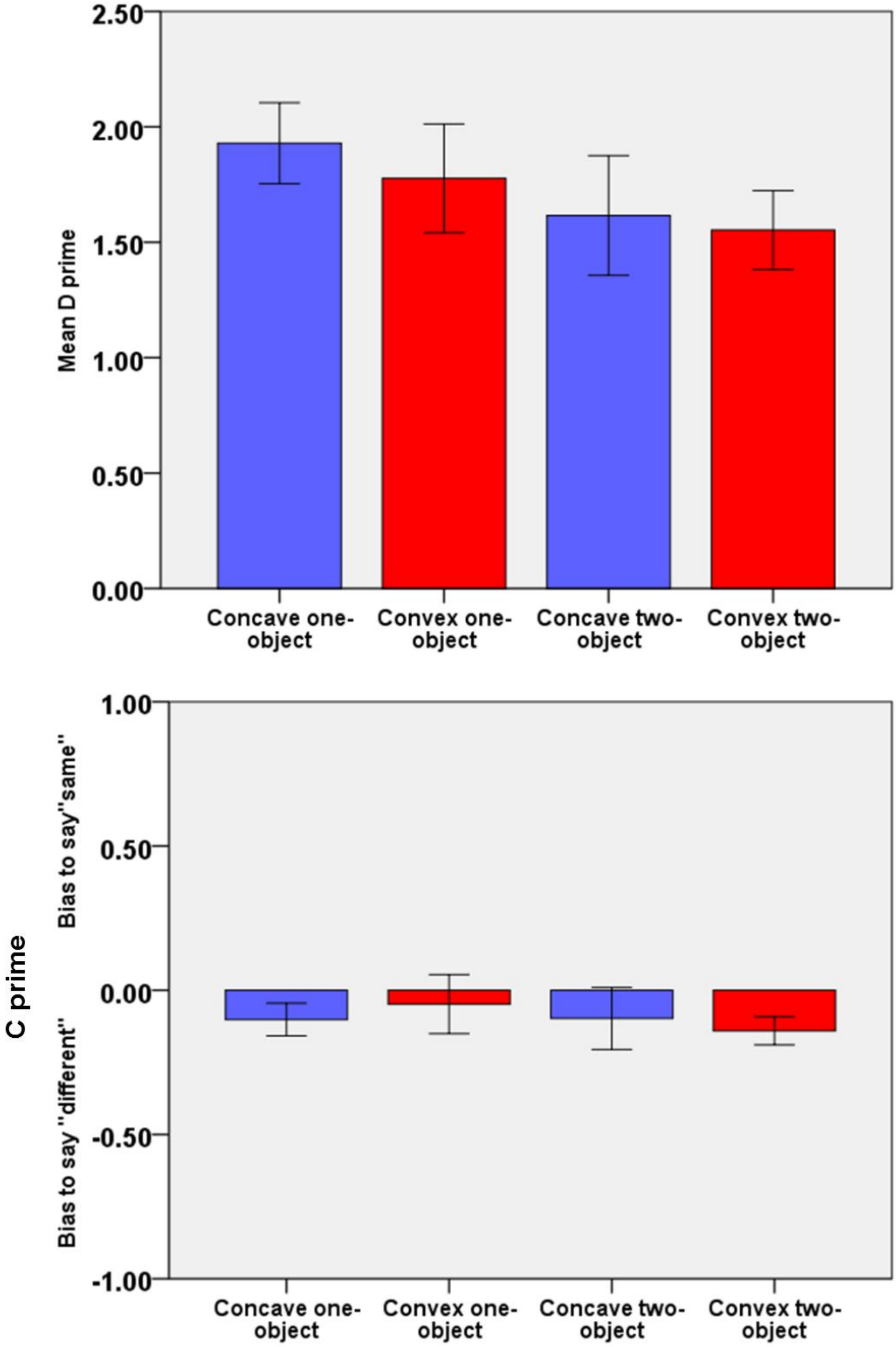


Figure 4.7. The sensitivity d prime and response bias for convexity and concavity and for one and two objects for Experiments 7a (Bilateral symmetry). Error bars are ± 1 SEM. Top row: d prime Bottom row: c. Blue bars: Mismatch in concavities; Red bars: Mismatch in convexities.

4.5 Experiment 7b (Translation)

Method

The purpose of Experiment 7b was to examine whether the effect of convexity advantage is specific of perceiving translational symmetry. Experiment 7b used the same design as Experiment 6b to test detection of translation instead of bilateral symmetry.

4.5.1 Participants

Sixteen members of the University of Liverpool community took part in the study (participants had a mean age 20 years, and the group comprised 12 female and 4 men).

4.5.2 Stimuli, design and procedure

Experiment 7b used the same methodology and stimuli as Experiment 6b, with the exception that one rather than two intervals were used throughout.

4.5.3 Results

The mean values for sensitivity and bias are shown in Figure 4.8. Performance was analyzed following the methodology used in Experiment 6a but there was only one factor: Convexity. This factor was significant for both sensitivity and bias. An ANOVA was performed with convexity (convex and concave condition) as within factors. There was a significant effect for convexity (F (1,15) =10. 68, p= 0.006, partial η^2=0.41).

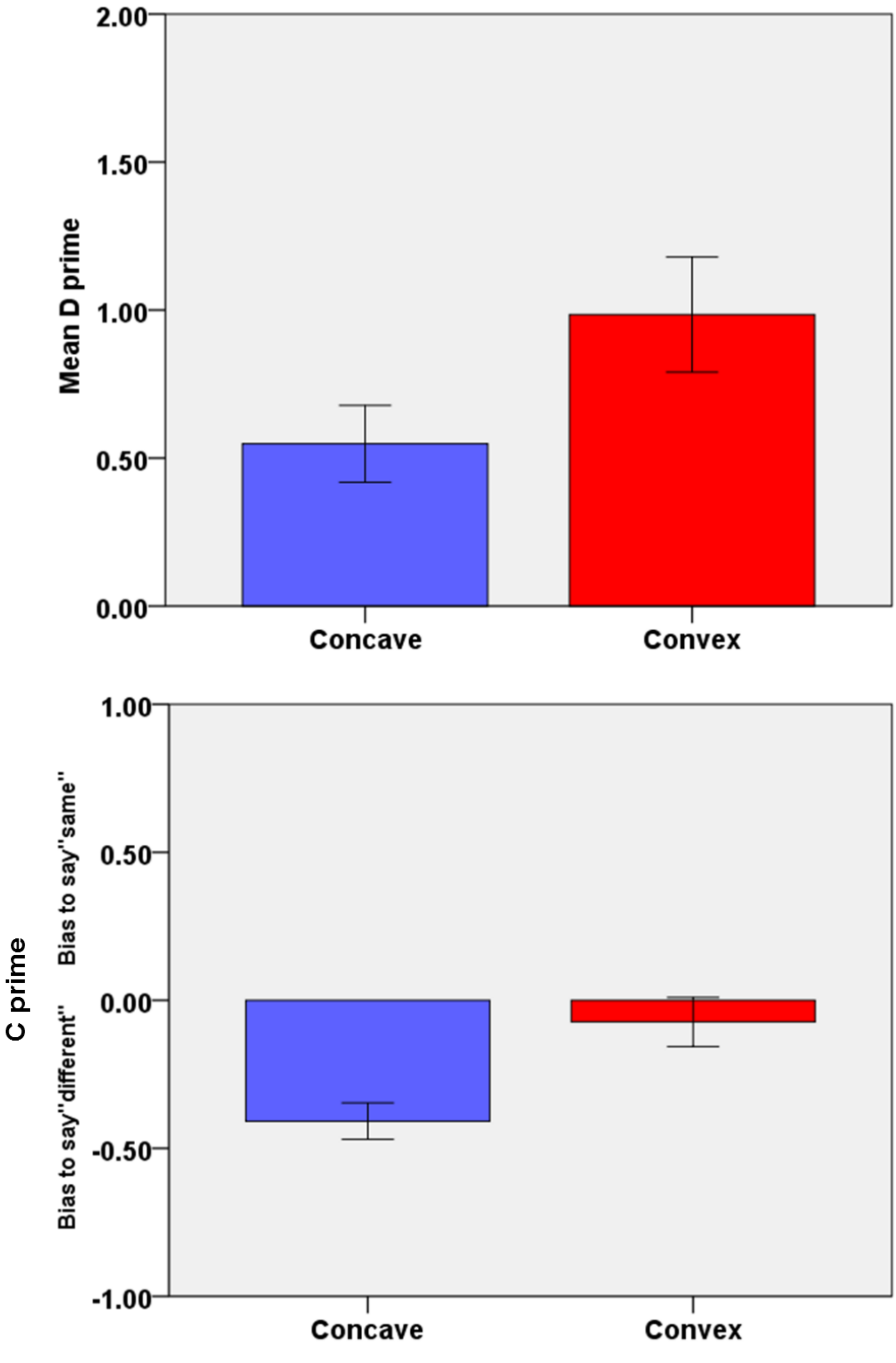


Figure 4.8. The sensitivity d prime and response bias for convexity and concavity for Experiments 7b (Translation). Error bars are ± 1 SEM. Top row: d prime Bottom row c. Blue bars: Mismatch in concavities; Red bars: Mismatch in convexities.

4.6 Experiment 8 (Comparing convex and concave as separate tasks)

Method

Experiment 8 used the same methodology as Experiments 6b and 7b to test the detection of repetition. This experiment tested the hypothesis that there is no difference between convexity and concavity in a situation where convexity and concavity were blocked. In Experiment 8, participants knew before taking part in the experiment that they would see stimuli with either a convex condition only or convex condition only; this was not the case in the previous experiments, and was included in order to support the hypothesis that participants tend to use the monitor strategy when the task is very challenging, requiring a considered response taking into account all conditions; where a task is less challenging (for example where the required response is based on a single condition only) this strategy is less likely to be used.

4.6.1 Participants

Sixteen members of the University of Liverpool community took part in the study (14 female and 2 male participants, with a mean age 20 years). All participants were assigned a 450 msec presentation time. Half of the group were tested first using stimuli with a convex condition, followed by stimuli a concave condition; this order was reversed for the other half of the group.

4.6.2 Stimuli, design and procedure

The stimuli, design and procedure were the same as those used in Experiments 1b and 2b.

4.6.4 Results

The mean values for sensitivity and bias are shown in Figure 4.9. Performance was analyzed following the procedure used in Experiments 6b and 7b. No difference in response was found between convexity and concavity; this factor was not significant for either sensitivity or bias. No difference was found between convex and concave conditions in sensitivity (F (1,15)=0.80, p = 0.38). No significant interaction in bias was found (F (1, 15) =0.16, p = 0.69).

An ANOVA was performed for convexity (convex and concave condition) as within and order as between, and no significant interaction was found between convexity and order for sensitivity either (F (1, 15) =2.75, p =0.11) or in bias (F (1,15) = 1.41, p =0.25).

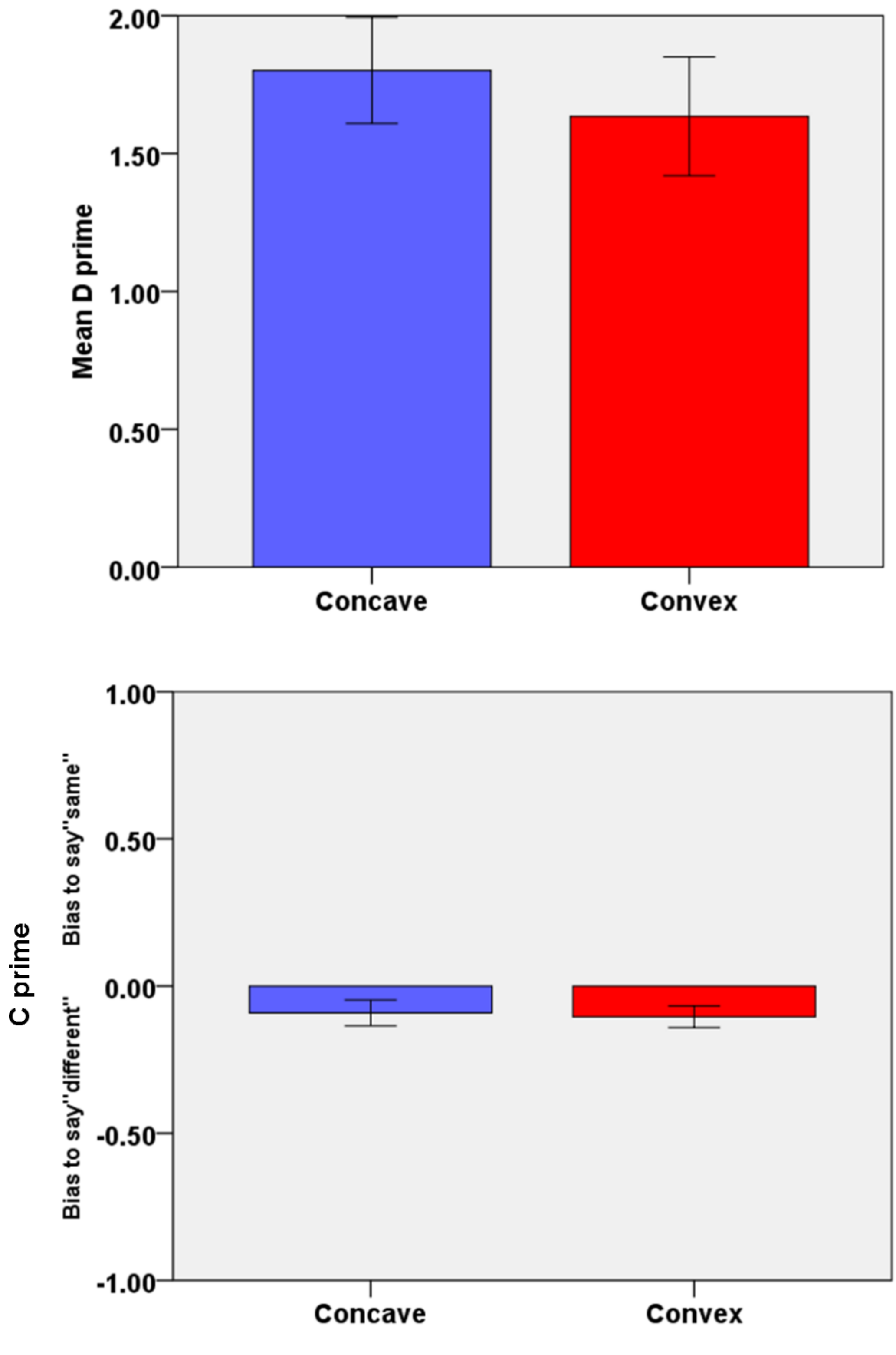


Figure 4.9. The sensitivity d prime and response bias for convexity and concavity for Experiments 8 (Translation). Error bars are ± 1 SEM. Top row: d' Bottom row c. Blue bars: Mismatch in concavities; Red bars: Mismatch in convexities.

4.6.5 Discussion

In general this study has found no evidence of an advantage for convexity in the perception of symmetry, although there is a clear convexity advantage for the detection of translated objects. It is possible that some methodological differences can explain the fact that Hulleman and Olivers' (2007) results were not replicated in the present study. In particular, the stimuli used in this study did not include a reference convex part in the lower region of the objects. With respect to the low sensitivity to concavities when detecting a translation (Experiment 7b) it is also possible that a monitoring strategy focusing on the convexities played a role, despite the instructions given to participants. Another interesting aspect of the data is the relatively large inter-individual variability: although in the instructions both concavities and convexities were described to the subjects (and they were told that the deviation from regularity could be in either), it is possible that some participants focused more on one region (convexities) and others on another region (concavities).

In summary the results of this study suggest that strategies play a role in the results gained, and potentially also in the original results from Hulleman and Olivers (2007). To test this possibility, the two tasks (using concave and convex stimuli) were separated in Experiment 8. Participants were asked to detect deviations from regularities carried by convexities in one set of trials and carried by concavities in another set of trials. Because of this change, participants were no longer faced with a choice about which region of the stimuli to assign priority to while they were monitoring shape information.

4.7 General Discussion

It has been highlighted by recent analyses that both convexity and concavity along a contour may be the foundations for the perception of shape. Many studies that have demonstrated effects of concavity and convexity, explain their empirical data in terms how aspects of contours are treated differently by the visual system. The empirical data fails to explain how advantages for both concavity and convexity are reported for different tasks, in the case of concavity; advantages have been found when using a change detection task (Barenholtz et al., 2003) and also when using the visual search paradigm (Hulleman et al., 2000; Humphreys & Müller, 2000). Whilst, probe discrimination (Barenholtz & Feldman, 2003), judgement of stimuli position (Bertamini, 2001) and detection of symmetry tasks (Hulleman & Olivers, 2007) have all been reported to convey advantages for convexity, other studies report that for tasks, such as change detection (Bertamini, 2008) or visual search (Bertamini & Lawson, 2006) there is no difference for concavity and convexity when the perception of part structure is unchanged between the two intervals.

These mixed results prompt an important question: does the mixed role of convex and concave regions in shape perception imply similarly different roles in the perception of symmetry? The first of the experiments outlined in this chapter demonstrated an advantage for changes in convexity relative to changes in concavity in a task requiring a comparison between two similar objects. Hulleman and Olivers (2007) found similar advantages for change in convexities, although they also reported advantages in comparisons between the left and the right side of symmetrical patterns (shown either within one object or across two objects).

The data from this chapter has shown no significant convexity advantage for bilateral symmetry (Experiment 6a and 7a). A significant effect was only presented for the comparing the features of translated objects, a condition that had not been previously tested by Hulleman and Olivers (Experiment 6b and 7b).

Methodologically there were some differences between this series of experiments and those conducted by Hulleman and Olivers. For the current series of experiments care was taken to create a situation in which concavity and convexity were as balanced as possible. In particular there were no differences in the total number of features perceived as being either convex or concave in each of the stimuli. The results of these experiments have shown to be more robust when comparisons are made across two different procedures (a two interval forced-choice, as seen in the original study, and a single interval detection task) and different measures of performance (percent correct and d prime).

To explain the findings of these experiments and their discrepancy with those of Hulleman and Olivers (2007), we investigated a potential tendency for participants to monitor convexities and whether this strategy was responsible for the convexity advantage. In order to test this assumption the experiment condition that demonstrated the clearest convexity advantage was replicated (Experiment 7b), but the task was separated into two blocks (Experiment 8). One block tasked participants with detecting a deviation from perfect translation located at convexities. The other block participants had to detect deviations at concavities. This modification had a significant impact on the results, completely removing the convexity advantage. Therefore, it can be concluded that convexities are special only in the sense that participants operate under a strategy which deploys more attention towards convexities when they are confronted with a task where it is impossible to monitor everything in the fixated visual space. This pattern of result will explain our findings and (Hulleman & Olivers, 2007) findings also, in particular there were differences in the total number of features perceived as being either convex or concave in each of the stimuli in their experiments . This pattern is believed to be consistent with the literature. Koenderink (1990) provided evidence which suggests that convexities tend to be perceived as one of the crucial features of an object. However this does not denote any basic differences when referring to visual processing or sensitivity. Other studies report that for tasks, such as change detection (Bertamini, 2008) or visual search (Bertamini & Lawson, 2006); there are no differences for concavity and convexity when the perception of part structure is unchanged between the two intervals. There are cognitive models of shape analysis and representation that utilize convexity and concavity information without assigning priority to one of them (Bell & Gheorghiu, 2009). Drawing on data from studies of adaptation, no difference between convexity and concavity has been noticed (Bell, Hancock, Kingdom, & Peirce, 2010). Suzuki (2003) reported evidence that inferotemporal areas code for convexity, though the convexity after-effect that was found by Suzuki is actually present for both convexity and concavity. However, a recent fMRI study has found an advantage for processing convexity over concavity in the anterior lateral occipital complex (Haushofer et al., 2008)

This monitor strategy is supported in the chapter addressing visual short-term memory, as in this chapter the participants have the ability to focus their attention on one condition and ignore the other. When detecting symmetry, participants show a preference for detecting convex conditions; but when detecting performance in visual short-term memory, they prefer to detect the change from convex to concave. This is consistent with the literature that convex vertices are more detailed and more organized relative to concave vertices (Bertamini, 2008; Bertamini & Lawson, 2008; Rosin, 2000; Pao, Geiger, & Rubin, 1999; Barenholtz, 2010).Moreover, this is also consistent with the findings of Kanizsa and Gerbino(1976), who showed that symmetry detection was easier for participants when they perceived a convex contour as a figure, and their responses were accurate when the figure was perceived as convex. Furthermore, this preference of convex vertices due to attentional advantage received by foreground regions, an observation which has been cited in a few different studies (Wong & Weisstein, 1982; Nelson & Palmer, 2007; Mazza, Turatto, & Umilta, 2005)

This evidence supports the results of this study, providing compelling evidence that the monitor strategy techniques found here are robust, and unlikely to be artefacts of the design of the experiment or the type of stimulus.

To return to the original aim point for this thesis (that is, the difference between convexity and concavity in perception of symmetry), the results presented here demonstrate that convexity plays an important role in detection of symmetry, but indirectly because of the use of a monitoring strategy.

CHAPTER 5| Contour ownership predicts shape interference

This chapter is adapted from Bertamini, M. Helmy, M.S., (2012). The shape of a hole and that of the surface –with-hole cannot be analysed separately. Psychonomic Bulletin & Review.

Abstract:

Background A hole within a surface can have an outline identical to that of an object. We designed an experiment to assess the extent to which figure-ground and contour ownership impacts shape processing: specifically the presence or absence of an interference effect. Results showed figure-ground assignment had strong impact upon shape recognition.

Methods We conducted a series of experiments on the interference between holes and objects to resolve the debate about the nature of hole. Therefore, my main goal in this study was to investigate how contours and figure ground organization contribute to shape interference. A test was created to assess whether shape processing is affected by contour ownership. Participants were required to distinguish between the shape of a contour which could be the same or different from a surrounding contour. The task was to decide whether a region was a square or a circle. The stimulus is presented either on congruent condition and non-congruent condition for object and hole condition. The congruent condition means that the shapes of the inside and outside regions were the same; On the other hand, the incongruent condition means that the shapes of the inside and outside regions were different.

Results Interference effects were stronger when the inside contour and the outside contour belonged to the same surface. Therefore, in all experiments the mean response time to the hole condition was significantly slower compared to the object condition.

Discussion The results of this study suggest that inside and outside contours produce an interference effect when they form a single object-with-hole, but not they form a hierarchical set of surfaces, or when they form a single hole separating different surfaces (trench). The conclusion is twofold, firstly which surfaces own the contour are the determinant of the interference between shapes, and secondly that despite claims to the contrary, holes display no form of object-like properties. The shape of the hole and that of the surface-with-hole cannot be analysed separately. Inside and outside contours produce an interference effect when they form a single object-with-hole, but not when they form a hierarchical set of surfaces, or when they form a single hole separating different surfaces (trench).

5.1 Introduction:

A small body of research literature discusses the perception of holes in 2D shape representation. Different researchers, typically utilising reaction time or visual search tasks to investigate this area, have varying perspectives. Researchers including Bertamini and Croucher (2003), regard holes as an integrated part of the structure of a shape, whereas others, such as Gillam and Cook (2001) consider holes to have a more specific importance in the perception of depth. A third perspective, held by Palmer et al., (2008) claims that the shape of a hole is easily encoded in memory, and that the shape of a hole can be processed as well as that of an object.

Following their study, Nelson and Palmer (2001) concluded that:

(1) When depth-based factors such as shadows, occlusion and continuation are positioned behind the surrounding region, holes may be more readily perceived.

(2) When the principles of Gestalt indicate that the inner and outer regions form one coherent object, or when the inner and outer contours likewise suggest a continuous form, holes may be more readily perceived in the closed area

(3) The shape of the surrounding area is important, and may itself be perceived as a hole. On top of a surface, convex, meaningful and complex shapes may be perceived as objects; whereas concave, meaningless, and simple shapes may conversely be recognised as holes through that surface (Nelson and Palmer, 2001).

The difference between perception of hole and the perception of an object is a strongly debated issue in the literature. Some studies have found differences between perception of objects and of holes while others have found similarities. We review this literature next.

Some researchers (Palmer, Davis, Nelson, & Rock, 2008 and Nelson, Thierman, & Palmer, 2009) have proposed that holes are encoded in memory as easily as objects.

On the other hand, Hulleman and Humphreys (2005) Bertamini and Croucher (2003) and Bertamini (2006) have proposed that holes and objects are treated differently.

We adopt the following definition of holes that is consistent with the aim of the study; a visual hole is a 2D region on a surrounding surface with a closed contour, which the human visual system can recognise as an aperture (Bertamini, 2006). Holes have a particular role in the study of shape, contour curvature, figure ground organization, and border ownership.

Albrecht, List, and Robertson (2008) used a task in which observers were faster to detect the target at a cued location relative to uncued location. The target could be either in front of a surface seen as an object or through a hole on a background surface. They concluded that when the location inside the hole is cued, the results suggest that the cued location is the surface visible through the hole because hole is consider as a ground region (Albrecht et al., 2008).

Through these various discussions about the relationship between holes and the areas surrounding them, researchers have identified a number of conditions related to the perception of holes (Bertamini & Croucher, 2003; Hulleman & Humphreys, 2005; Nelson & Palmer, 2001). Bertamini and Croucher (2003) suggested that the perceived contour belongs to the surrounding region, rather than to the hole itself. They reached this conclusion by examining the manner in which the human visual system encodes holes within shapes, using two regions. These regions differed in the relative position of convexity or concavity vertices. The researchers found that the judgments of position for concave vertices are slower than similar judgments for convex vertices. The relationship of stimuli between figure and ground leads to a perception of both a hole and an object. In conclusion, the shape of boundary was found to be assigned to the surrounding area, not to the holes themselves (Bertamini & Croucher, 2003; Bertamini, 2006). In addition, many researchers including Bertamini and Lawson (2006), and Hulleman and Humphreys (2005) have performed visual search tests to investigate the perception of regions as either holes or objects and they found mixed results.

The difference between holes and objects was investigated by Hulleman and Humphreys (2005). They used a search task in which participants were asked to search for a "C" shape among a set of "O" shaped distracters. In these stimuli the “O” could be perceived as a hole or an object. The researchers found that participants were easily able to distinguish the target when perceiving the “O” shapes as objects, but faced difficulty in identifying the target when the “O” shapes were perceived as holes (Hulleman & Humphreys, 2005).

Bertamini (2006) discussed an early example of a phenomenon that used holes to study figure-ground organization. As suggested by Arnheim, (1954), “A” may be recognised as a figure because it is convex, but “B” is perceived as a hole because it concave (see Figure 5.1).

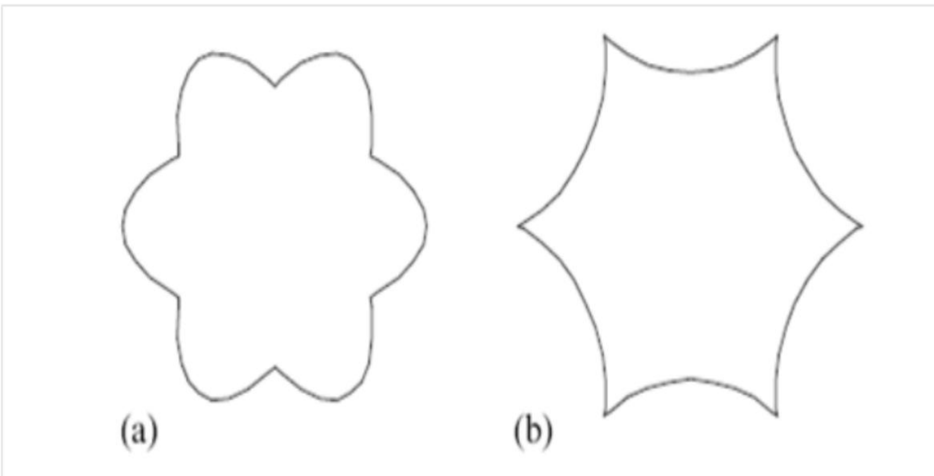


Figure5.1. Arnheim illustrated perceived of (a) object and (b) hole shape.

As concluded by Bertamini and Croucher (2003) a contour that surrounds a hole is assigned to the surrounding object, it is obvious that the encoded information depends on the change between hole and object. In their study participants were asked to appraise the position of one vertex relative to another vertex (whether it was lower or higher vertically), and two different types of stimulus were used: an hourglass and a barrel shape (hole and object respectively). When the barrel shape was perceived as a figure, due to the convex contour, participants found it easier to compare positions. Likewise, participants were likely to judge the position of the hourglass shape as a hole, because the contour could be identified as a convex contour belonging to the surrounding area. The test results clearly indicated that judging the position of the shapes as objects was faster for the convex/barrel stimulus than for concave/hourglass stimulus. Similarly, when judging the position of the local surround as the object (with the stimulus perceived as a hole in that object), the advantage is inverted and performance with the hourglass was better than with the barrel. In other words, it is easier to judge the position of convex vertices for Barrel shaped object and the Hourglass-shaped hole. This result was corroborated by Bertamini and Mosca (2004) with their research using stereograms. Bertamini and Croucher (2003) explained that in the case of concave contours, the contours were identified as belonging to the local surround, not to the inner hole. The surrounding object for the hourglass seen as a hole was perceived as having convex vertices, but for the barrel hole the object had concave vertices. Bertamini and Croucher suggested that "a hole is defined by the contour of the enclosing object, rather than the hole itself possessing the contour" (p. 52). Furthermore, Bertamini and Mosca (2004) demonstrated that positional information always directed to convex vertex because it contains a lot of information and perceived as a figure. Thus, the change of the figure ground organization; from a figure to a hole or from a hole to a figure always changed the coding of the curvature as a convex region or as a concave region (Bertamini & Mosca, 2004).

The asymmetry between visual searches for concavities and convexities was tested by Bertamini and Lawson (2006). The search for concavities is generally regarded as more useful for visual search than the search for convexities, and when the target is closer from the concave region the response is more rapid. Finally, the researchers suggested that the search for a hole among objects is easier than the search for an object among holes. Nevertheless, they concluded that there is no any advantage of concavity over convexity, although concavity plays a potential role that it is impossible to ignore in perceiving part structure (Bertamini & Lawson, 2006).

This is consistent with the findings of Nelson, Thierman, and Palmer (2009), who found no difference between objects and holes in a memory task; intrinsic holes are faster to remember relative to accidental holes. In the beginning they discriminate between intrinsic holes and accidental holes in perception of shape; intrinsic holes surrounded by all sides with a single surface, rather than accidental holes surrounded by a lot of surfaces and occurred as a coincidence. They argued that intrinsic holes of shapes are easier to remember because intrinsic hole act as an "immaterial surface" that belong to an object, whereas accidental holes do not belong to an object and consequently, it is hard to remember them(Nelson et al., 2009).

Horowitz and Kuzmova (2011) found that it is relatively easy for people to track both holes and objects. They used the multiple objects tracing (MOT) method as it helps to understand the units that created attention: participants were asked to track four stimuli from a choice of eight moving stimuli (either holes or objects). The study concluded that it is no easier or more difficult for participants to identify holes than objects or vice versa. For example, tracking was faster when a blank background was visible, as opposed to a complex background.

In summary from the above studies, contours confer information about solid shape; consideration of line drawings can be said to easily demonstrate this. The tendency seems to be for the perception of contours to be the borders of a particular surface, in that it describes the actual surfaces itself and not the regions of ground. This principle is termed unidirectional contour ownership (Koffka 1935; Nakayama, Shimojo, & Silverman, 1989; Rubin, 1921). A critical element that allows vision to work properly is knowing what should be perceived as figure and what should be perceived as ground (Humphreys, 1999). Interest into the understanding of figure-ground seemed to emerge at the start of the last century, the applications of which has been seen beyond just psychology; contour ownership has a role in understanding perceptive fields of neurons responsible for shape analysis (Lamme et al., 2002; Zhou et al., 2000) and image segmentation into figure-ground is important in computational models of vision (Tek & Kimia, 1995).

A key debate in figure-ground literatures is about the shape analysis of a ground region. Peterson and her colleagues (Peterson & Skow-Grant, 2003) hold the position that before figure assignment, familiarity (previously seen objects) and configural cues (convexity, closure, symmetry) are used to evaluate both sides of a contour. The implication of this is that foreground and background share an early stage where both regions are processes in terms of shape. This clearly demonstrates that ground regions are not shape-less and more specifically, that figure-ground organization is influenced by past experience. Peterson has also introduced the idea that, in the case of apertures, it is possible to produce figure-figure segmentation where both regions are given figural status as well as being able to have figure-ground segmentation. Figure ground organization has been demonstrated to have a central role in visual perception as it facilitates the creation of regions to which features, such as shape descriptions, are then assigned. There is however some disagreement as to how much dependency shape analysis has on figure-ground. The purest form of a figure-ground organization is comes from the perceived reversal in figure-ground of a closed region. The resulting perception from this reversal is that of either an object or a hole.

This study aims to test that contour ownership determines the presence or absence of interference when the 2D contour information is identical between 2 regions; even for simple shape analysis. We used a task in which figural relationships are irrelevant. Moreover, this task does not involve memory, which avoids the possibility of hole shape judgment being affected by memory of the object-with-hole instead of the perceptual response.

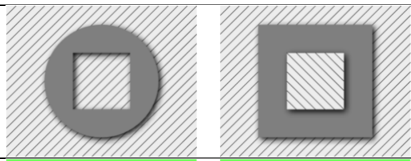
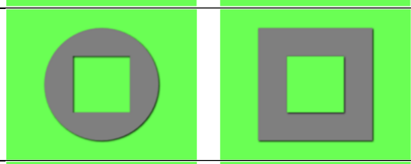
Experiment title	Experiment aim	Stimuli
(9) Experiment 9.	To test the shape interference by using texture and shading to create a sense of surface layout.	
(10) Experiment 10.	As Experiment 9 with the exception that the using shading alone.	
(11) Experiment 11.	As Experiment 10 with the exception that using a minimal amount of shading.	
(12) Experiment 12.	We changed depth relations so that the object surface was coplanar with the background, and separated from it by a trench.	
(13) Experiment 13.	We have increased the uncertainty of where the object stimuli were presented (they appeared in one of four quadrants) while the hole stimuli were more central.	We used the same stimuli and design of Experiment 10.
(14) Experiment 14.	We introduced a secondary task. After judging the shape observers were also reporting on whether the stimulus was perceived as an object or as hole.	We used the same stimuli and design of Experiment 10. In this experiment the stimulus disappeared after 200 msec and this is not the case in the previous experiments.

Table5.1. This table is illustrates the shape interference experiments; Exp 9 texture and shading, Exp 10 shading alone, Exp 11 minimal shading, Exp 12 changed depth (a trench around them), Exp 13 appeared in one of four quadrants, and Exp 14 dual task.

Each trial began with a 2000 msec fixation period, followed by stimulus presentation, which was maintained until the participant responded. Stimulus presentation occurred either in the congruent (the shape of the inside and outside regions are identical) or non-congruent condition (the shape of the inside and outside regions are different). Figure 5.2 shows the 'congruent hole' condition of Experiment 9. In this condition both inside and outside regions were squares, and the dark background was extended to the entire screen. In this condition, facilitation (a faster response) should occur; when regions are different, interference (a slower response) should occur; expectations which have been developed from the 'Flanker procedure' (Eriksen & Schultz, 1979). The Flanker task operates by creating distractor stimuli which flank the target stimulus, potentially activating other responses. The target stimuli and distractor are associated with one response in the congruent condition and with competing responses in the incongruent condition. Flankers activate the response associated with these stimuli which increases response time in incongruent compared to congruent trials. Because our task is about shape, but figural relationships are task-irrelevant, we can test whether shape analysis can occur separately to figure-ground organization. This sets our methodology apart from other studies. This methodology also avoids the problem of the hole shape judgments being based on memory of the object-with-hole because memory is not involved in the task: the same relevant region of space was attended to spatially in either perceived region (object or hole).

One factor which may interfere in the experiment is depth stratification. Previous research has shown that depth can also require attention. This effect needs a high number of distractors and a high perceptual load (Arnott & Shedden, 2000; Atchley et al., 1997). In our methodology, the only difference in depth was in the direction of seperation between surfaces, and depth was ordinal: the 'hole' was defined as the region farther away from the participant, the 'object' the region closer. The issue of location of depth will be further explored in Experiment 12.

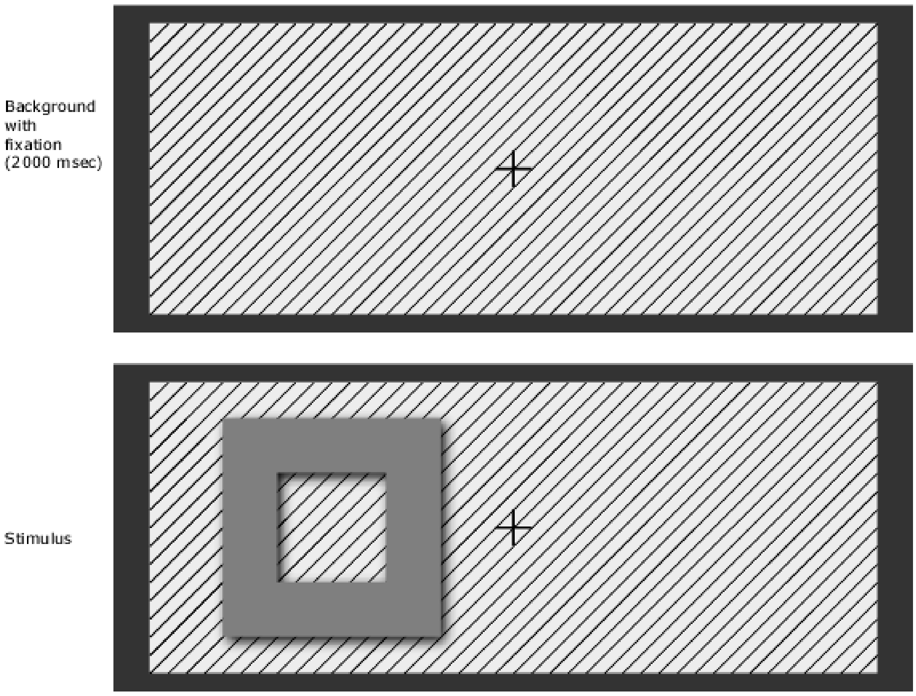


Figure5. 2. The example shows the congruent hole condition of Experiment 9 in which both inside and outside regions are squares.

In Experiment 9 we used texture and shading to create a sense of surface layout. But in Experiment 10 we used shading alone (Experiment 10), and a minimal amount of shading (Experiment 11). Finally, we changed depth relations so that the object surface was coplanar with the background, and separated from it by a trench (Experiment 12). In Experiment 13 we have increased the uncertainty of where the object stimuli were presented (they appeared in one of four quadrants) while the hole stimuli were more central. In Experiment 14 we introduced a secondary task. After judging the shape observers were also reporting on whether the stimulus was perceived as an object or as hole. In all cases interference from the outside shape on the perception of the inside shape was present only when both contours (inside and outside) belonged to the same surface. In this sense a hole cannot be treated as a proto-object because contour ownership determines how contours are perceived and represented, even when contour ownership is task irrelevant.

General method

Stimuli. The stimuli were presented on a monitor (resolution 1024X 768 at 85 Hz) controlled by an Apple Macintosh computer. Presentation and storage of the data was controlled by a program written in C++ and OpenGL. The total height of the stimulus was 0.8 deg and the height of the central region was 0.3 deg. The shading was generated by a gaussian-blurred black region displaced toward the lower right corner by 0.140 deg, except in Experiment 11 where the displacement was 0.70 deg. This corresponds to lighting from top left, which is the preferred direction for human observers (Mamassian & Goutcher, 2001). The only source of illumination in the room was a light placed on the left side and higher than the monitor so that real lighting and direction of shading were consistent.

Design. There were four factors involved in. These are: the shape of the central region (whether it was square or circle), congruency (whether the shape of the inner and outer regions were the same or different), objectness (whether the shapes were objects or holes) and location of the stimulus (whether the stimulus was located to the left or the right). The stimulus was placed to the left or to the right for two reasons. Firstly, this ensures that participant attention is evenly spread over the entire stimulus. Secondly, the dark shadows tend to be directed more towards the right when the central region is an object compared to being a hole, and this asymmetry in the shadow location is balanced. This is important because if shadow location affects response time then objectness should interact with stimulus location. In Experiment 14 the stimuli were presented centrally but they remained visible only for 200 msec.

Procedure. Each observer sat in a dimly illuminated room at a distance of approximately 57 deg from the monitor. During a trial a fixation cross was presented for 2 seconds, and next the stimulus was presented to the left or to the right of fixation.

In Experiments 9, 10, 11, 12 and 13 the stimulus remained visible until the participant had responded. In Experiment 14 the stimuli disappeared after 200 msec. We did not monitor fixation because the exact location of the fixation is not critical for our studies. Participants pressed the “z “key or the “/” key to indicate that the shape was a square or a circle, respectively. In Experiment 14 this speeded response was followed by a second task, prompted by a question on the screen, in which observers reported whether they had seen an object or a hole. Each experiment started with 15 practice trials, followed by 192 experimental trials. After each block of 64 trials a message appeared and the observer was allowed time to rest. The start of the subsequent blocks was self-paced.

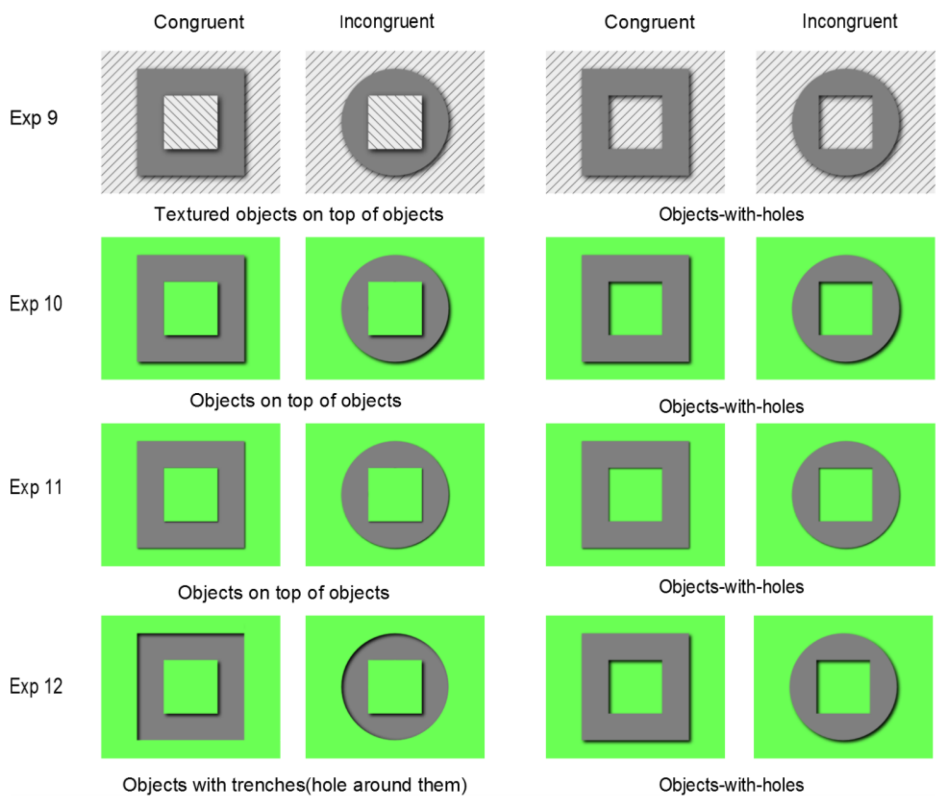


Figure 5.3. Examples of stimuli used in Experiments 9, 10, 11 and 12. For each condition, each pair of images shows a congruent stimulus (on the left) and an incongruent stimulus (on the right).

5.2 Experiment 9

5.2.1 Participants

Ten members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (M = 20 years, 6 Female) were involved.

5.2.2 Procedure

We used the same procedure in all experiments see description in the procedure section.

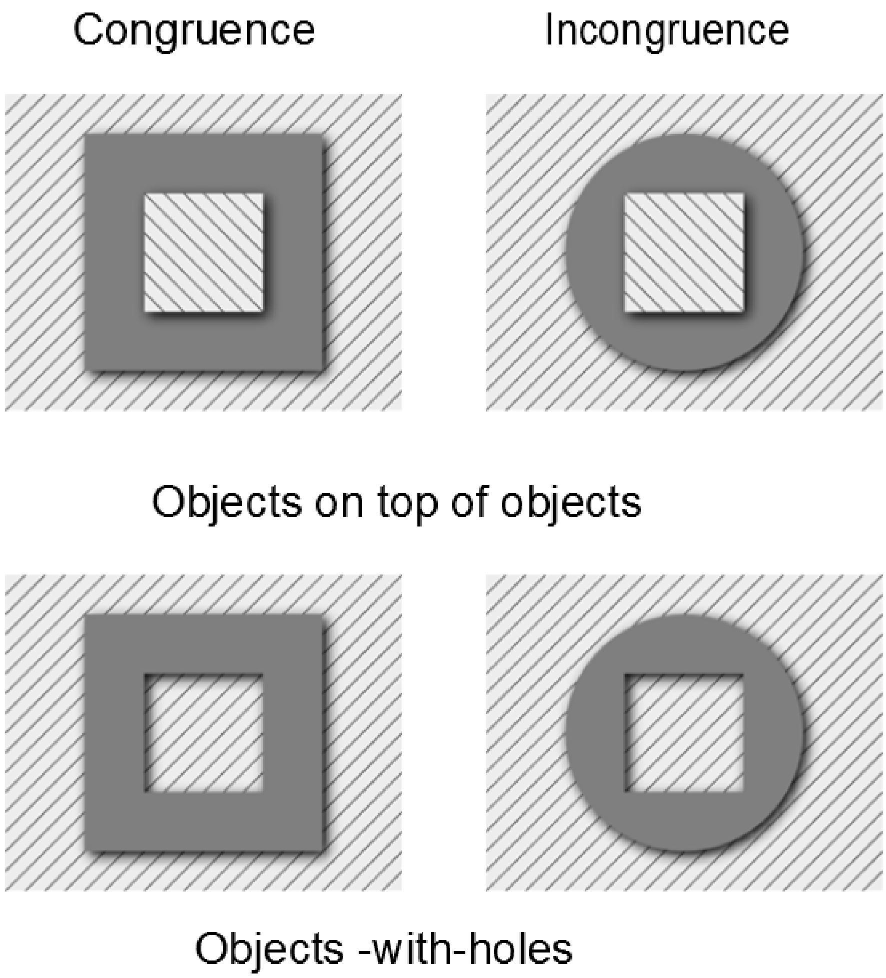


Figure 5.4. Examples of stimuli used in Experiment 9. In each row there is a congruent stimulus and an incongruent stimulus.

5.2.3 Results

We performed a repeated-measures ANOVA with objectness (object and hole), congruency (congruent and incongruent), and location (left and right) as within-subjects factors. There was a significant effect of objectness: responses to objects were faster (F (1, 9) =28.21, p<0.001, partial η^2 = 0.76), an effect of congruency: responses were faster in the congruous condition (F (1,9)=30.77, p<0.001, partial η^2= 0.77), and an interaction between objectness and congruency (F (1,9) =18.72, p=0.002, partial η^2 = 0.68). To test the congruency effect for the hole condition and for the object condition separately we performed two additional t-tests and adjusted alpha to 0.025. For holes, responses in the congruent condition were faster than in the incongruent condition (t (9)= 4.98, p<0.001). For objects there was no difference (t (9) =1.51, n.s.). Because interference was stronger in the hole condition, we conclude that holes cannot be processed independently of the surface that belong to.

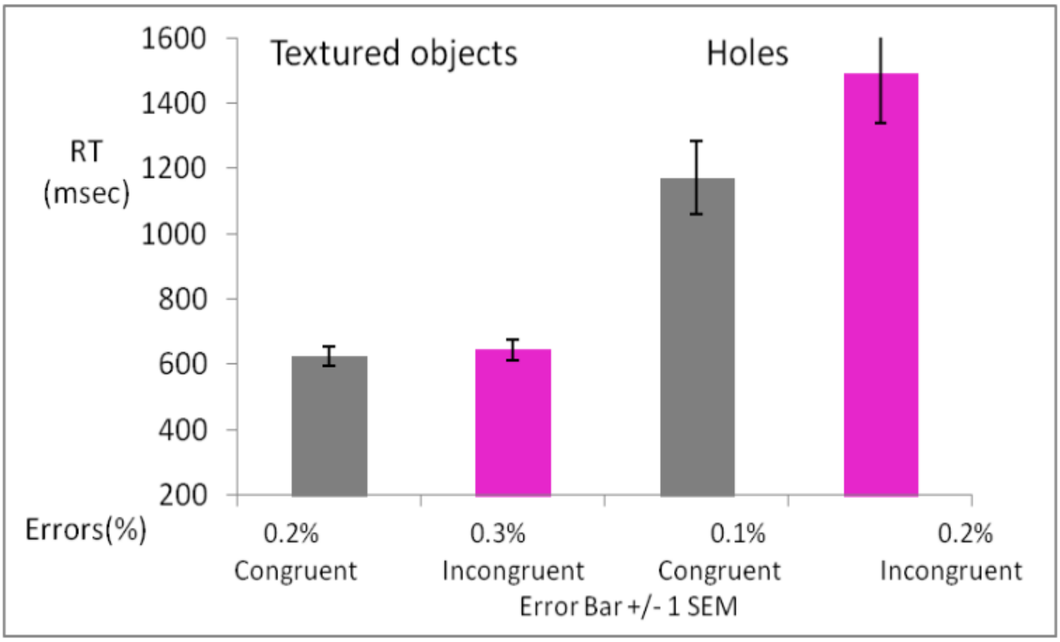


Figure 5.5. Results from Experiment 9. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects and holes. Underneath the bars I also report mean error rate.

5.3. Experiment 10

In Experiment 10 relies on shading alone, and not on changes in texture, to specify foreground and background regions. We used a uniform green surface as shown in Figure 5.6.

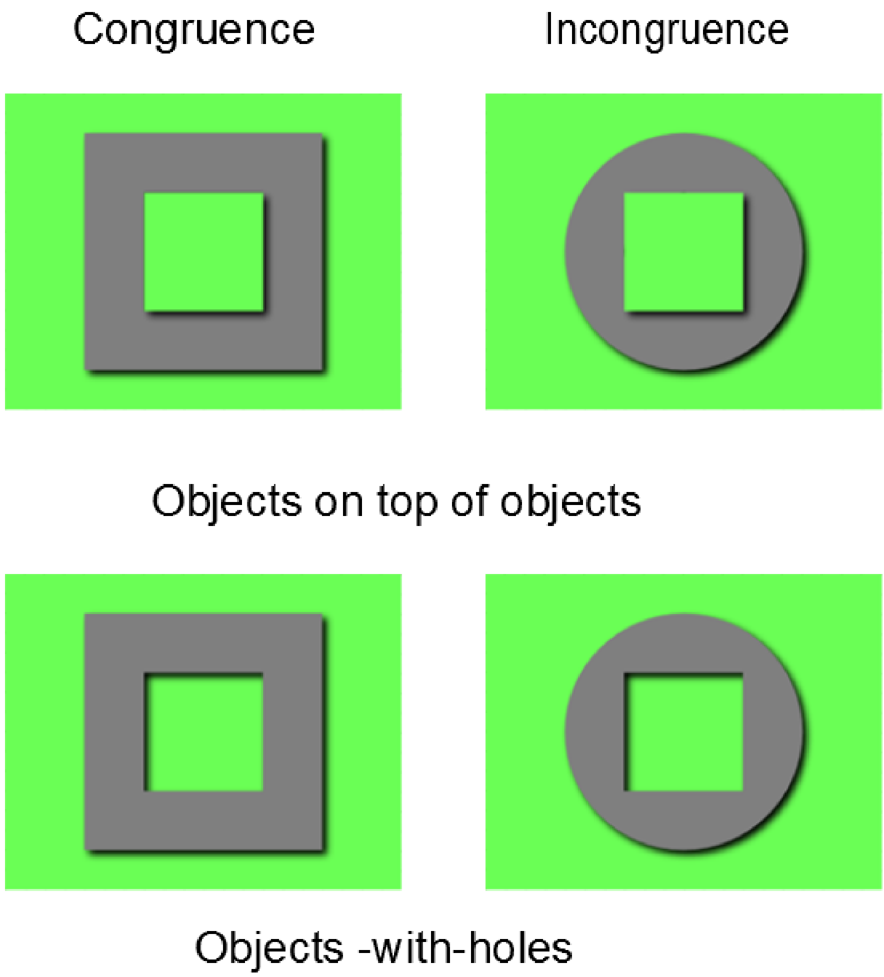


Figure 5.6. Examples of stimuli used in Experiment 10. In each row there is a congruent stimulus and an incongruent stimulus.

5.3.1 Participants

Ten members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (*M* = 20 years, 7 Female) were involved.

5.3.2 Procedure

We used the same procedure in all experiments see description in procedure section.

5.3.3 Results

A repeated-measure ANOVA with objectness, congruency, and location as within-subjects factors was performed. There was a significant effect of objectness: responses to objects were faster (F (1, 9) =27.43, p=0.001, partial η^2 = 0.75), an effect of congruency: responses were faster in the congruous condition (F(1,9) =22.42, p=0.001, partial η^2 = 0.71), and an interaction between objectness and congruency (F (1, 9) =30.79, p<0.001, partial η^2= 0.77). To test the congruency effect for the two conditions separately I performed two additional t-tests and adjusted alpha to 0.025. For holes, responses in the congruent condition were faster than in the incongruent condition (t (9) =5.34, p=0.001). For objects there was no difference (t (9) =-0.67, n.s.).

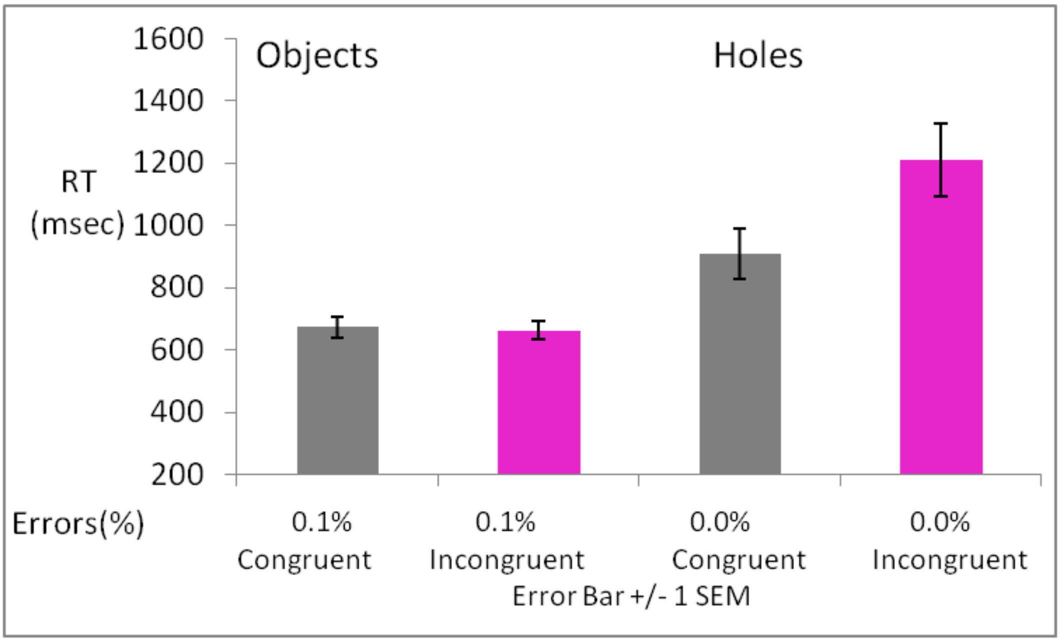


Figure 5.7. Results from Experiment 10. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects and holes. Underneath the bars I also report mean error rate.

5.4 Experiment 11

Experiment 10 confirmed the same interaction as Experiment 9. Shading is therefore powerful enough to generate this effect. In Experiment 11 we reduced the length of the shadow by half to test whether this weaker version would also confirm the same pattern (see Figure 5.8).

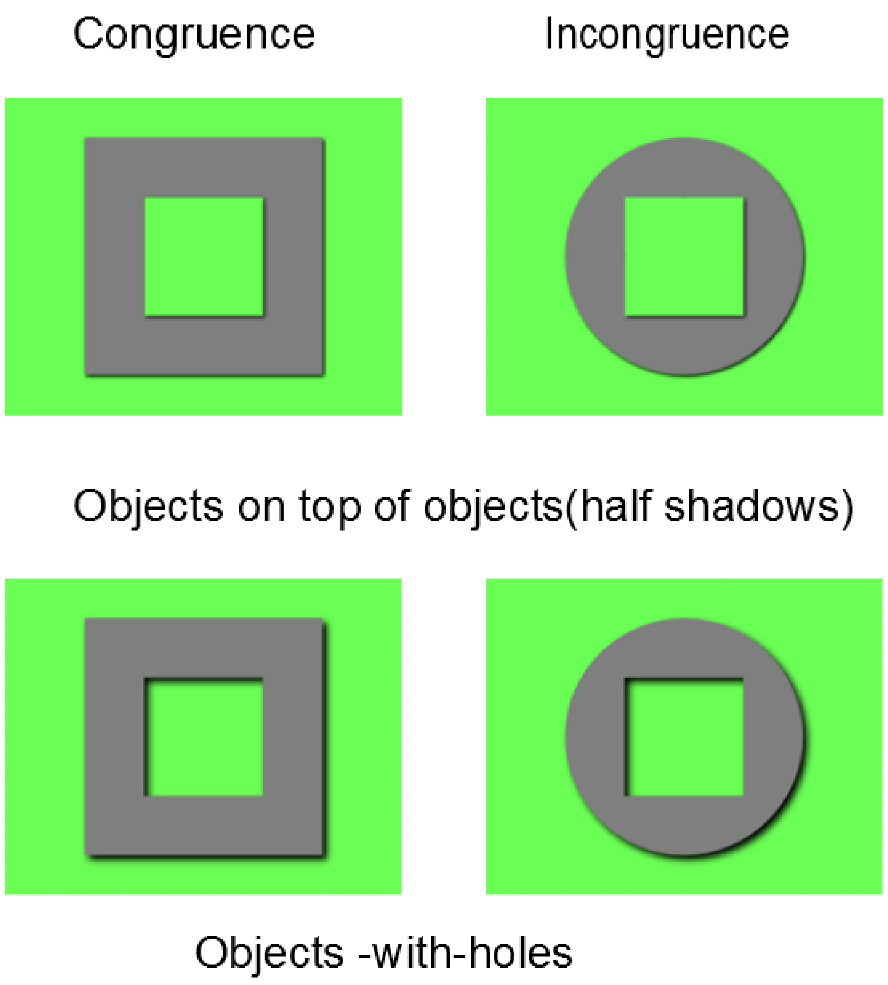


Figure 5.8. Examples of stimuli used in Experiment 11. In each row there is a congruent stimulus and an incongruent.

5.4.1Participants

Ten members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (*M* = 20 years, 8 Female) were involved.

5.4.2 Procedure

We used the same procedure in all experiments see description in procedure section.

5.4.3 Results

A repeated-measure ANOVA with objectness, congruency, and location as within-subjects factors was performed. There was a significant effect of objectness: responses to objects were faster (F (1,9) =32.13, p<0.001, partial η^2 = 0.78), an effect of congruency: responses were faster in the congruous condition (F (1,9) =38.55, p<0.001, partial η^2 = 0.81), and an interaction between objectness and congruency (F(1,9) =30.47, p<0.001, partial η^2=0.77). To test the congruency effect for the two conditions separately we performed two additional t-tests and adjusted alpha to 0.025. For holes, responses in the congruent condition were faster than in the incongruent condition (t (9) =5.86, p<0.001). For objects there was no difference (t (9) =-2.59, n.s.).

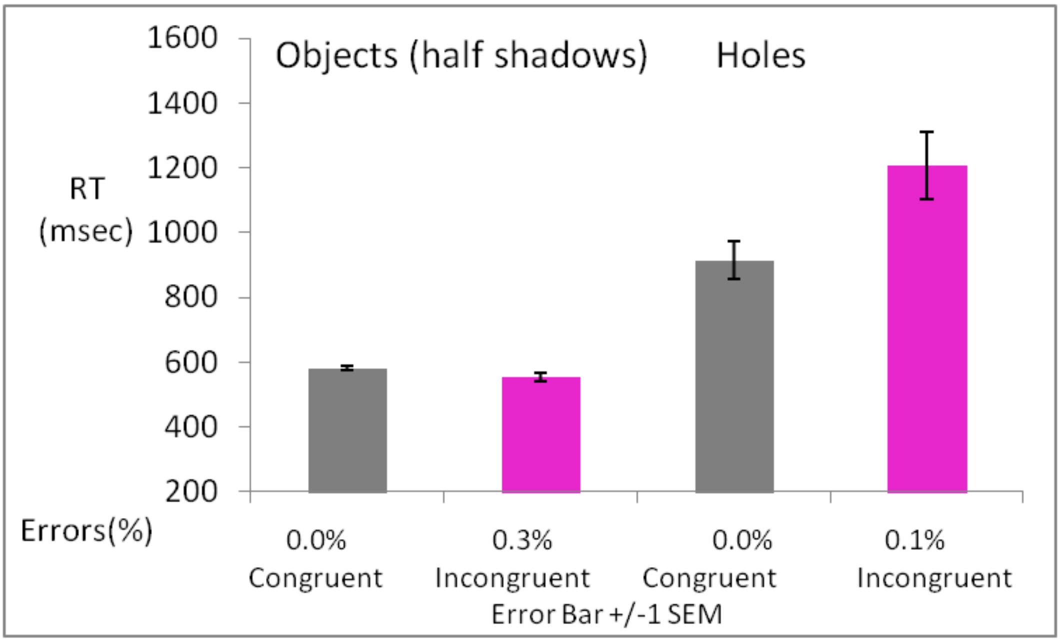


Figure5. 9. Results from Experiment 11. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects with half shadows and holes. Underneath the bars I also report mean error rate.

Combined analysis.

We performed a mixed ANOVA with objectness, congruency, and location as within-subjects factors, and version (9, 10, or 11) as a between subjects factor. There was a significant effect of objectness: responses to objects were faster (F (1, 27) =82.23, p<0.001, partial η^2=0.75), an effect of congruency: responses were faster in the congruous condition (F (1,27) =86.01, p<0.001, partial η^2= 0.76), and an interaction between objectness and congruency (F(1,27) =76.31, p<0.001, partial η^2 = 0.74). To test the congruency effect for the hole condition and for the object condition separately we performed two additional t-tests and adjusted alpha to 0.025. For holes, responses in the congruent condition were faster than in the incongruent condition (t (29) =9.55, p<0.001). For objects there was no difference (t (29) =-0.81, n.s.). Because interference was stronger in the hole condition, we conclude that holes cannot be processed independently of the surface that they belong to. In this sense a hole region cannot be treated as quasi-figural because contour ownership determines how contours are perceived and represented, even when contour ownership is task irrelevant.

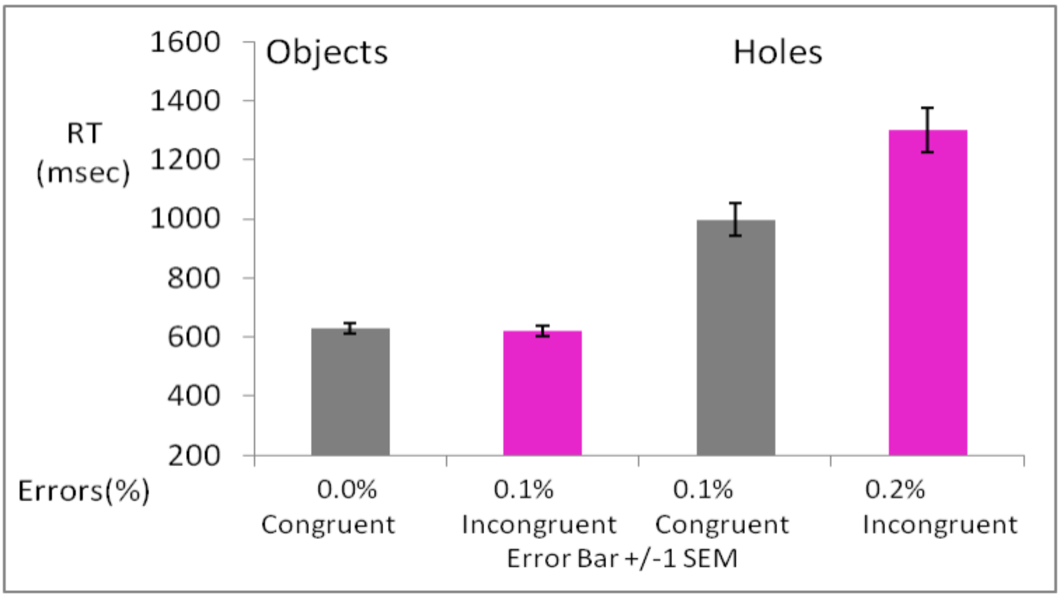


Figure5. 10. Results from combine (three experiments). For each condition the bars show the mean response time for the congruency and incongruence conditions for objects and holes. Underneath the bars I also report mean error rate.

5.5 Experiment 12

In Experiment 12 we tested the hypothesis that the interference effect is linked to the condition where contours are perceived as located in the same depth. In this Experiment we make the inside and outside contour belong to the same coplanar surface; we achieved that by putting a trench around them. We have increased the sample for Experiment 12 to 20. In this Experiment both conditions now include holes but we predict that interference will not present be present when the holes form a trench.

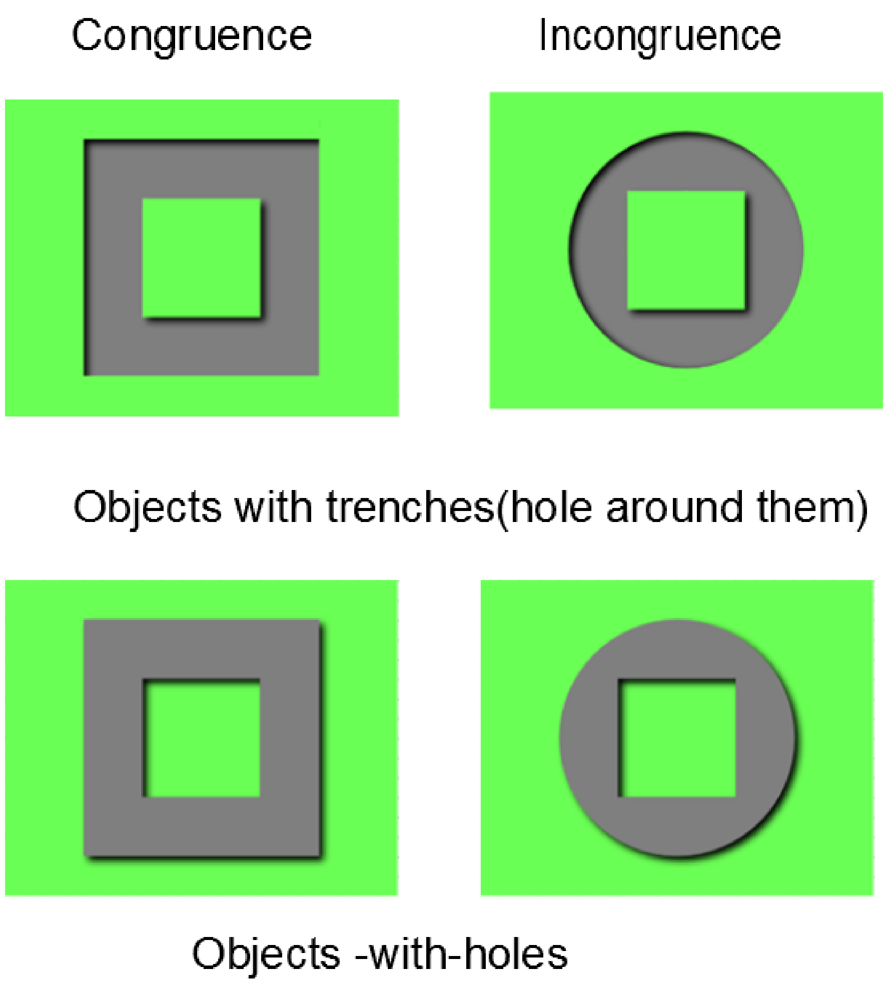


Figure 5.11. Examples of stimuli used in Experiment 12. In each row there is a congruent stimulus and an incongruent stimulus. The above shows objects with trenches and bottom objects with holes.

5.5.1Participants

Twenty members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (*M* = 20 years, 12 Female) were involved.

5.5.2Procedure

We used the same procedure in all experiments see description in page 165.

5.5.3 Results

A repeated-measure ANOVA with objectness (trenches and holes), congruency, and location as within-subjects factors was performed. There was a significant effect of objectness: responses to trenches were faster ($F(1,19) = 232.04$, $p<0.001$, partial $\eta^2 = 0.92$), an effect of congruency: responses were faster in the congruous condition (F (1, 19)= 245.79, $p<0.001$, partial $\eta^2= 0.92$), and an interaction between objectness and congruency (F (1,19) =133.57, $p<0.001$, partial $\eta^2 = 0.87$). To test the congruency effect for the two conditions separately we performed two additional t-tests and adjusted alpha to 0.025. For holes, responses in the congruent condition were faster than in the incongruent condition (t (19) =14.17, $p<0.001$). For trenches there was no difference (t (19) =3.60, $p<0.01$.

Given that trenches are a type of holes the difference between the two conditions in Experiment 12 cannot be described as a difference between objects and holes. Interference can be absent for holes as long as the contours of the region to be judged and the contours of the irrelevant region are not shared by the same surface. It may be concluded that although both conditions included holes there is no interference when the hole forms a trench. Moreover, the interference was present when the outside and inside of object belonged to the same surfaces, and therefore this experiment is important in showing that a depth difference is not a critical factor in generating the interaction. It is interesting that the difference between congruent and incongruent conditions is 45 msec for the trenches and 532 msec for the holes. For a task in which the contours to be judged are the same, this difference is large as confirmed by the strength of the interaction.

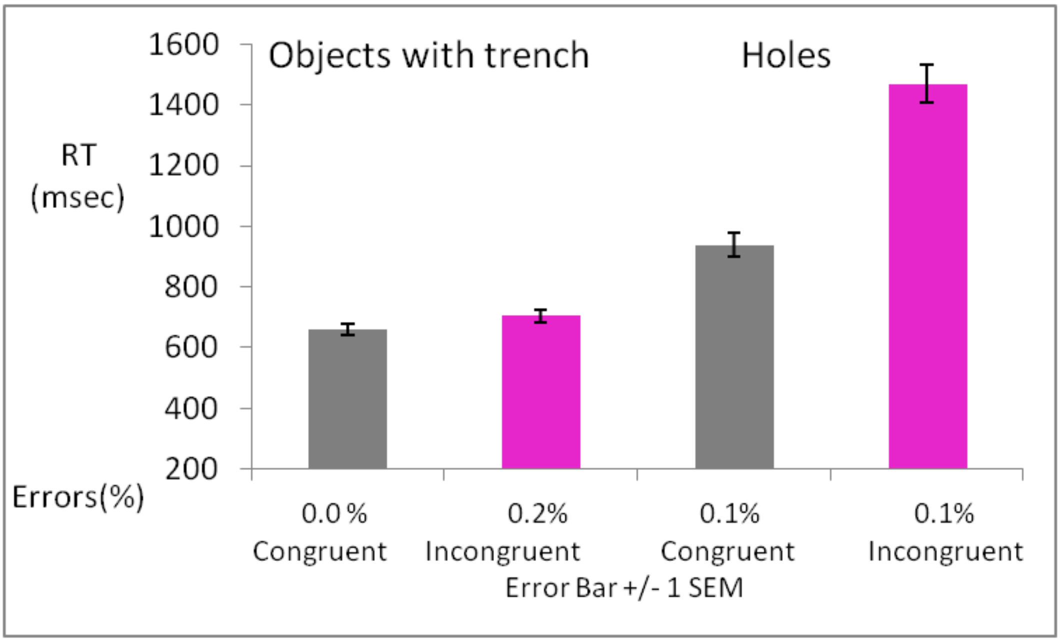


Figure 5.12. Results from Experiment 12. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects with trench and holes. Underneath the bars I also report mean error rate.

5.6 Experiment 13

One aspect of the results is a significantly slower response to holes compared to objects. Experiment 13 attempted to reduce this factor while at the same time not changing the stimuli per se which are matched on several important dimensions (shape, size, luminance and contrast). We used the same stimuli and design of Experiment 10 but we increased the uncertainty of where the object stimuli were presented (they appeared in one of four quadrants) while the hole stimuli were more central. This way the physical properties of the stimuli were fixed, but we expected responses to the object stimuli to be slower and to the hole stimuli to be faster. This was the case relative to the previous experiments, although a reduced difference remained (with responses to objects still slightly faster). The fact that in Experiment 13 longer saccades were necessary to reach the object stimuli made us wonder whether eye movements were playing a role in all our results. Perhaps it is easier to foveate an object than a hole.

5.6.1Participants

Ten members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (M = 20 years, 9 Female) were involved.

5.6.2 Procedure

We used the same procedure in all experiments see description in procedure section.

5.6.3 Results

Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis. The excluded data was 3.3 %.

A repeated-measure ANOVA with objectness (objects and holes) and congruency as factors was performed. There was a significant effect of objectness: responses to objects were faster (F (1,9) =24.42, p<0.001, partial eta squared= 0.73), an effect of congruency: responses were faster in the congruent condition (F (1,9) =73.10, p<0.001, partial η^2 = 0.89), and an interaction between objectness and congruency (F(1,9) =5.35, p>0.04, partial η^2=0.37). This analysis confirmed a strong interaction between objectness and congruency. Responses to objects were still faster than responses to holes, but when compared to Experiment 10 they were slower than in the comparable object condition (t(18)=3.17, p=0.005 and not different than in the hole condition(t(18)=1.94, n.s).

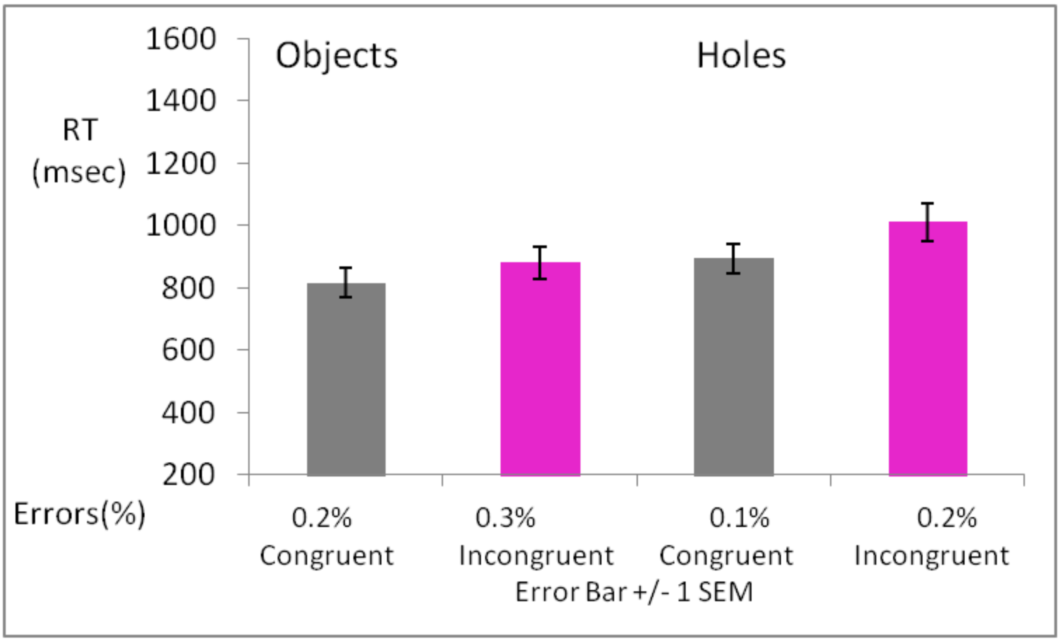


Figure5. 13. Results from Experiment13. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects and holes. Underneath the bars I also report mean error rate.

5.7 Experiment 14

In Experiment 14 we asked the observers to perform an additional task and report whether they had seen an object or a hole. One advantage of this study is that it provides direct evidence of the fact that the shadows affect the percept in the predicted way. In some trials the stimulus was perceived as reversed (i.e. what normally is perceived as a hole was perceived as an object and vice versa). The response time for this additional task are not being timed. The stimuli in this Experiment were the same as Experiment 10. In this experiment the stimulus disappeared after 200 msec and this is not the case in the previous experiments. Therefore in Experiment 14 the stimuli were all presented at fixation and for a limited amount of time (200 msec) to look at fixation effects. One of the reasons for doing that is to test whether different fixations will have the same outcome or not. One of the explanations is that the longer time for hole condition because observers' fixation is directed at the outside of the object-with-hole.

5.7.1Participants

Fifteen members of the University of Liverpool community took part in the study and received course credit for participation. They had normal or corrected to normal vision. Ages ranged from 18 to 22 (*M* = 20 years, 13 Female) were involved.

5.7.2 Procedure

We used the same procedure in all experiments see description in procedure section.

5.7.3 Results

Error trials and outliers (RT more than 3 standard deviations from the mean) were excluded from the analysis. The excluded data was 3.9%. A repeated-measures ANOVA with objectness (objects and holes) and congruency as factors was performed. There was a significant effect of objectness: responses to objects were faster (F (1, 14) =86.64, p<0.001, partial η^2=0.86), an effect of congruency: responses were faster in the congruous condition (F (1,14)=108.54, p<0.001, partial η^2= 0.88), and an interaction between objectness and congruency (F (1,14) =39.01, p<0.001, partial η^2 = 0.74). This analysis confirmed a strong interaction between objectness and congruency.

On the secondary task participants performed very well when asked to decide whether the stimulus they had seen was an object or a hole. The results confirmed that they perceived stimuli as predicted. Trials in which they made an "error" (reporting seeing an object in the case of a hole or vice versa) were infrequent (4.9%). Nevertheless it is interesting to note that F value and the effect size of the objectness and congruency interaction increased after removing this trials.This is reassuring in that it confirms that holes were perceived as holes and objects as objects.

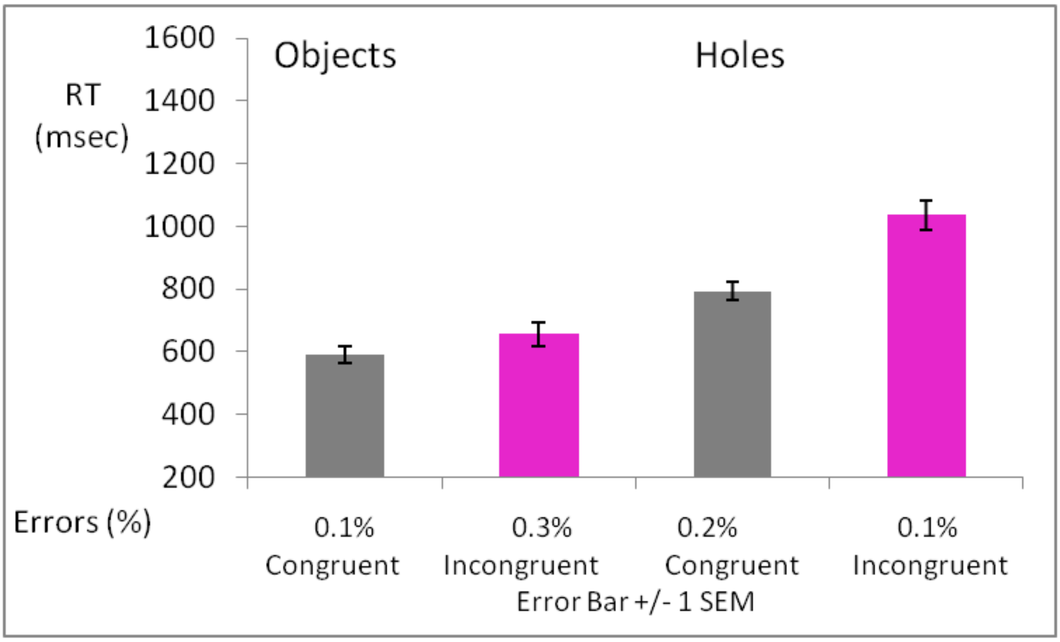


Figure 5. 14. Results from Experiment14. For each condition the bars show the mean response time for the congruency and incongruence conditions for objects and holes. Underneath the bars I also report mean error rate.

5.8 General discussion:

Holes can specify locations in a visual space; it has been shown that attention can be directed towards this location in a visual search (Bertamini & Lawson, 2006) or in multiple objects tracking (Horowitz & Kuzmova, 2011). When analysing shape of a region, there is no evidence that holes possess quasi-figural properities. Thus holes are not an exception to the principle of unidirectionality in contour ownership.

This study involved the use of a simple task in which participants had to discriminate between a circle and a square. The two conditions of congruency (congruent or incongruent) were manipulated by using outside regions that appeared as either a circle or a square. As hypothesised, incongruent conditions resulted in slower response times when compared with congruent. However, throughout all experiments this effect was strengthened when the same surface was shared by both inside and outside contours. The implication of these findings is that surfaces are computed quickly and contour ownership in relation to surface ownership plays a role in shape processing.

These findings concur with the assumption that contour ownership and object segmentation are crucial factors, with the role of depth separation, difference in eye movement and surface properities being unimportant.

Relating back to task difficulty the discrimination between circular and square regions is simple and therefore only required responses to basic features such as size and line terminators. It is possible then that in this experiment target onset maybe responded without the need for focused attention. This suggests that pre-attentive representation differ between regions perceived as either a whole or as an object (proto-objects). These findings are contrary to recent claims that the visual system analyses the shapes of holes as if they were figures (Feldman & Singh, 2005; Palmer et al., 2008) or that holes behave as proto-objects. Instead we provide evidence for a view that says regions of both holes and objects are fundamentally different as far as shape analysis is concerned.

The changing of texture (Experiment 9 versus 10), or of extent of the shadow (Experiment 10 versus 11), were shown to have little effect on the results. Interactions occurred when contrasting holes with trenches (a stimulus where all contours are perceived as lying on the same plane (Experiment 12). This interaction remained even when responses to holes were faster due to them being presented near the fixations point (Experiment 13) and when the stimulus presentation time was only 200 msec (Experiment 14).

The finding that response time for the hole condition was significantly slower compared to the object condition can be explained by two factors. Firstly processing of additional shape information take place in the hole condition which causes said interference. Secondly, hole stimuli carry a certain amount of ambiguity thus requiring a longer response time. The reasoning behind the second explanation being that fact that closure only exists as a figural factor meaning that in the case of the hole stimuli the closed region is not a figure. Only when the hole is accurately distinguished as a property of another surface, of which the hole is a figural component, can the ambiguity be resolved.

Regarding the interference effects, namely the flanker task, faster responses have been known to propagate the strongest interference (Gratton, Coles, & Donchin, 1992; Stins, Polderman, Boomsma, & Geus, 2007). Thus it is doubtful that the varying response times is an intervening factor responsible for the interference effects that have been reported as a result of this study, as interference was demonstrated in slower but not the faster of the two conditions. The high speed of the response may also be due to attentional advantage received by foreground regions, an observation which has been cited in a few different studies (Wong & Weisstein, 1982; Nelson & Palmer, 2007; Mazza, Turatto, & Umilta, 2005). However, foreground advantages in and off itself cannot explain these interference effects, as the object-with hole is foreground surface.

Results of this experiment have shown to coincide with the finding of other studies comparing holes and objects. Bertamini and Farrant (2006) gave evidence to suggest that perception of part structure of regions depend upon whether the region has been specified as either a hole or an object within random dot stereogram. The use of stereogram's has also been seen in studies by Gillam and Cook (2001) which found that, because a trapezoid hole does not have ownership of its contours, its shape did not have an effect on the perceived slant of the surface viewed as being within that particular region. Hulleman and Humphreys (2005) used a search task in which participants were asked to search for a "C" shape among a set of "O" shaped distracters. Using a letter as stimuli gave the possibility for the “O” to be perceived as both a hole and an object. The researchers found that participants were easily able to distinguish the target in when perceiving the “O” shapes as objects, but faced difficulty in identifying the target when the “O” shapes were conversely perceived as holes (Hulleman & Humphreys, 2005).

Casati and Varzi (1994) have written extensively about the ontology of holes. Using the term" superficialities" to describe holes they eloquently capture the tenable link between holes and the surface that it belongs to. If this link were being broken the hole would cease to be perceived as a hole. The results of this experiment expresses a link between the hole shape and the shape of the surface-with-hole, suggesting that neither of these can be analyzed separately even when the task requires the categorization of the whole region itself.

In brief, the results of these tests on the incongruency effect between inside and outside contours provide evidence that surfaces which own the contour are the determinant of the presence/absence of interference between shapes, and despite claims to the contrary, holes display no form of object-like properties. The shape of the hole and that of the surface-with-hole cannot be analysed separately. Therefore, inside and outside contours produce an interference effect when they form a single object-with-hole, but not they form a hierarchical set of surfaces, or when they form a single hole separating different surfaces (trench).

CHAPTER 6| General Discussion

6.1 Introduction

Perception of visual shape and attention can be influenced by local convexity and concavity coding along a contour. The effects of convexity and concavity have been demonstrated experimentally, and empirical data has been explained in the context of the visual system treating aspects of contours differently. According to the evidences in the present studies, it may be concluded that convexity and concavity regions play an important role in visual perception of shape. It has been highlighted by recent analyses that convexity and concavity along a contour may be the foundations for the perception of solid shape and part structure (Hoffman & Richards, 1984; Koenderink, 1984). Thus many studies that have demonstrated effects of concavity and convexity, explain their empirical data in terms of how aspects of contours are treated differently by the visual system. However, the experimental evidence does not explain why or how there are advantages for both convexity and concavity in different tasks.

Differences between convexity and concavity in change detection have been reported on some detection tasks (Barenholtz, Cohen, Feldman, & Singh, 2003), but when other factors were eliminated Bertamini (2008; see also Bell, Hancock, Kingdom, & Peirce, 2010) found similar levels of performance. However, a privileged coding of convexity (higher sensitivity in LOC) has been reported in a recent fMRI adaptation study by Haushofer, Baker, Livingstone, and Kanwisher (2008). Convexities have also been found to be more important in a symmetry detection task (Hulleman & Olivers, 2007). Other studies report that for tasks, such as change detection (Bertamini, 2008) or visual search (Bertamini & Lawson, 2006); there is no difference between concavity and convexity when the perception of part structure is unchanged between the two intervals.

We have compared convexity and concavity by using different tasks and a range of stimuli containing corners or features in a change detection task. In this task only one of the features could change and shapes were repeated rather than reflected in symmetry. Furthermore, the figure ground organization was used to determine the relationship between contour and shape interference. Compelling evidences revealed that the differences between convexity and concavity are robust. We conclude that convexity plays a role detection of symmetry (translation symmetry), but there is no basic difference in how convexities and concavities are processed in the corner enhancement effect, and in visual short -term memory.

6.2 Aims

The aim of the present study is to investigate the difference between convex and concave parts in the corner enhancement effect, visual short term memory performance, perception of symmetry perception, and congruency effect in perception of simple shapes.

In this chapter we will summarise the results in relation to the differences between convexity and concavity in visual perception in different tasks. Drawing on previous literature and current results, we reached the following conclusions:

(1) The experiments reported in chapter two found that responses were faster when a probe was located near a corner compared to a straight edge. This effect, called the corner enhancement (Cole et al., 2001), was found for both convex and concave vertices when the probe was near the corner of the foreground surface. However, the effect was absent when the probe was not located on the foreground surface. In summary, the

corner enhancement effect was present only when the probe was on the surface that owns the corner.

(2) The experiments reported in chapter three did not confirm a basic sensitivity difference between convexity and concavity in storing the information in visual short-term memory. Chapter three provided evidence that there is no role of convexity as such in visual short-term memory. However, there was some evidence for an advantage for the closed contour on processing of shape over the baseline condition.

(3) It has been claimed that convexity is important in detection of symmetry. This effect could be found when two similar objects are compared. Chapter four reported evidence that this convexity advantage exists for translated contours. However, there is a strategy that participants used when they monitor a convexity condition, but it disappears when the convexity and concavity conditions are not mixed in the same set of trials.

(4) The role of contour ownership in determining the degree of interference between shapes is demonstrated in chapter five. In these experiments it was found that interference effects were only present when an inside contour and an outside contour belonged to the same surface (with a hole in it).

In the next part of this final chapter we will present the main conclusions in relation to the corner enhancement effect, Visual short-term memory, Symmetry, and shape interference in details.

6.3 Corner enhancement effect

Chapter 2 investigated a phenomenon known as the corner enhancement effect. The procedure involved responding to a probe that could appear near a corner or near a straight edge. The results of these experiments replicated the finding previously reported by Cole et al., (2001) and also extended the explanation in terms of demonstrating that an advantage is seen only when the probe is perceived to be on the surface that owns the corner.

In terms of methodology we used colored surfaces seen monocularly and we used shading to create a sense of surface layout. A second manipulation extended the findings to surfaces specified by binocular disparity alone, and to do this we used random dot stereograms to make foreground and background non-ambiguous. In chapter 2 we report a set of experiments that used stimuli similar to those used for the shape interference.

Two experiments were conducted. These experiments used a simple task involving the discrimination of orientation for a probe (horizontal and vertical). Coloured regions with cast shadows were used to unambiguously distinguish foreground and background (monocular shading and binocular disparity along with stereograms), as well a square region that could be perceived as either object or hole (a figure-ground reversal). In the object condition, a square surface lay on top of a circular surface, and vertices were consequently perceived as convex. In contrast, in the hole condition, a square hole lay embedded within a circular surfaces, and vertices were consequently perceived as concave.

The corner enhancement effect was found to be present for both convex and concave vertices, as long as the probe lay upon the corner-owning surface. Furthermore, the interaction between the corner and the surface disappeared when the probe did not lie upon the corner-owning surface.

This provides support for the corner enhancement effect. Cole et al (2001) first reported evidence that corners were easier to recognize in convex regions than straight edge. Therefore in Experiments 1d and 2c the probe is a new object that is not located on the surface, in the sense that it is not perceived as attached to it. Perceptually the probe no longer belonged to any specific surface and would be viewed as floating.

By comparing results from Experiments 1a-2a with results from Experiments 1b-2b we can compare the corner enhancement effect for convex and concave corners. The difference between the two versions of the experiment was the location of the probe, inside the central region (1a-2a) or outside the central region (1b-2b). This manipulation had a clear effect as the corner effect was present for convex corners in 1a-2a or was present concave corners in 1b-2b. This change can be explained by noting that in the first case the probe was perceived on the surface that had convex vertices (the central object) and in the second case the probe was perceived on the surface that had concave corners (the object-with-hole).

Based on this hypothesis we conducted further experiments. In Experiment 1d-2c the probe was perceived as a separate object that was detached from the other surfaces. As a consequence no significant corner enhancement effects were found. We conclude that the corner enhancement effect depends on the probe appearing not only near a corner in the image but also near a corner that was owned by the surface.

We compared our findings of the corner enhancement effect with respect to the findings by Cole et al., (2007). Our results demonstrate that there is a link between the type of the object (hole or surface with hole) and the corners (corner enhancement effect and straight-edge). Finally, we conclude that which surface owns the probes determines the presence or absence of corner enhancement effect.

6.4 Visual short-term memory

A memory task was used to test possible differences between convexity and concavities in a series of experiments. There is controversy in the literature, on the evidence for a difference in change detection performance between convexity and concavity. Some studies had demonstrated that detection of a change involving a concavity is easier than detection of a change involving a convexity (Cohen, Barenholtz, Singh, & Feldman, 2005; Bertamini, 2008). In our experiments convex and concave segments of a contour were directly compared, and this had not been done before using a standard VSTM paradigm. We conducted three experiments on the issue, examining the difference between convexity and concavity in VSTM.

Experiment 3 examined the difference between short-term memory for convexities and for concavities and no convexity advantage was found. However, participants were better at remembering closed contour compared to a baseline condition with just a contour segment. We call this a closure advantage. Thus, there is no difference between convexity and concavity in VSTM. This agrees with the literature because closure is a factor that enhances shape detection (Elder & Zucker, 1993) and modulates shape adaptation (Bell, Hancock, Kingdom, & Peirce, 2010).

In Experiment 4 we found that the closure advantage disappeared if the region changed from the left to the right side between intervals. This manipulation causes a change from convexities into concavities and vice versa. Therefore observers saw convex features in the first intervals but had to judge the change after seeing concave features in the second interval (or vice versa). This supports our hypothesis that the convexity advantage might be due to strategic choices made by the participants. If the participants were preferentially monitoring the convexities, they would be less sensitive to changes from concave to convex, because they are attending to the wrong part of the figure. We have made an attempt to resolve theses mixed results. Experiment 5 confirmed the importance of closure using a within subject design. We suggest that convexity and concavity are therefore an important aspect of shape analysis and representation, but that there is no basic difference in sensitivity to changes to convexities and concavities.

It was found that performance improved in closed condition relative to baseline condition. Moreover, performance improved in closed condition that did not change relative to the closed condition that did change. Therefore, it is arguable that convexity and concavity are important aspects of shape analysis and representation, but there is no basic difference in how convexities and concavities are processed. It therefore seems that the convexity and concavity advantages reported are due to the demands of the specific tasks used in the experiments rather than any intrinsic differences between the perception of convexities and concavities.

6.5 The role of convexity in perception of symmetry

It has been explained, in the introduction, that symmetry plays an important role in human perception. Hulleman and Olivers (2007), for example, state that deviations from symmetry carried by convexities were easier to detect than deviations carried by concavities. Three further experiments on the theme were conducted. In Experiment 6a, we failed to replicate the convexity advantage reported by Hulleman and Oliver (2007), but it broadly agreed with them in terms of the trend in the data. When I tested detection of repetition (translation) instead of symmetry we found a convexity advantage for repetition (6b) similarly to the advantage for bilateral symmetry found by Hulleman and Oliver (2007). This pattern of results was replicated in Experiment 7 in which the methodology was changed and instead of two intervals observers had to judge the presence of symmetry in a single interval. In our data, the advantage for convexity was only present for comparing features of translated objects, a condition that Hulleman and Olivers did not test (Experiment 6b and 7b).

An alternative explanation of our results and Hulleman and Olivers' results is that observers may adopt a strategy in some tasks to focus their attention on some region of the image, and they may choose to focus on convexities. In Experiment 8 we tested if there is any difference between convexity and concavity if we blocked convexity and, after that, blocked concavity. The reason blocking may be important is that under these conditions observers know where they should focus their attention. In Exp 8 it was revealed that there was no difference between convexity and concavity even for translation. Therefore, any sign of a convexity advantage disappeared when people did not need to choose which region to monitor. It is possible that a monitoring strategy focusing on the convexities played a role, despite the instructions.

Another interesting aspect of the data is the relatively large inter-individual variability. Although in the instructions both concavities and convexities were described to the observers and they were told that the deviation from regularity could be in either, it seems possible that some observers focused more on one region (convexities) and others on another region (concavities). Therefore, the findings of chapter 4 were replicated despite the change of stimuli and change of task; we have comparable effects of monitor strategy technique for both visual short-term memory and perception of symmetry.

It has been concluded that convexities are special only in that participants strategically pay more attention to them when confronted with a difficult task in which it is impossible to monitor everything. We believe that this pattern agrees with the literature. Convexities tend to be perceived as the important features of an object (e.g., Koenderink, 1990), but this does not imply any basic difference in terms of visual processing or sensitivity.

6.6 Contour ownership predicts shape interference

We have now considered the results from studies on the difference between convexity and concavity for the corner enhancement effect, in visual short-term memory, and for perception of symmetry. In chapter 5 we examined whether contour ownership determines the degree of interference between shapes, following on from the results in the corner effect. These new set of studies did not directly relate to convexity and concavity, but used similar stimuli to those used in chapter 2. Except that they relate to a reversal of figure ground that also causes a reversal of convexity and concavity.

Six experiments were conducted. In Experiment 9, we examined the textured objects on top of objects and objects-with-holes (figure 5.4). A significant interference effect was found for objects-with-holes but there was no interference effect for textured objects on top of objects. This was interpreted as support for the role of figure ground organization in shape interference.

In Experiments 10 and 11 shadows were used without any change in the textured, but in Experiment 11 we reduced the amount of shading. We found significant differences between objects-with-holes and objects on top of objects. Participants were faster when the objects on top of objects and they take longer time when the objects belong to holes. Thus, in Experiment 12, we used different objects not as in Experiments 9, 10, 11. We used stimulus lying on the same depth of the outline. In Experiment 12 we tested the hypothesis that the interference effect is linked to the condition where contours are perceived as located in the same depth. In this experiment we make the inside and outside contour belong to the same coplanar surface; we achieved that by putting a trench around them.

In this experiment we made the inside and outside contour belong to the same depth plane; we achieved that by putting a trench around them. It may be concluded that although both conditions included holes there is no interference when the hole forms a trench. Moreover, the interference was present when the outside and inside of object belonged to the same surfaces, and therefore this experiment is important in showing that a depth difference is not a critical factor in generating the interaction. In Experiment 13, we attempted to resolve the faster response in object conditions. We have increased the uncertainly of where the object stimuli were presented (they appeared in one of four quadrants) while the hole stimuli were more central. The fact that in Experiment 13 longer saccades were necessary to reach the object stimuli made us wonder whether eye movements were playing a role in all our results. Perhaps it is easier to foveate an object than a hole. Therefore in Experiment 14 the stimuli were all presented at fixation and for a limited amount of time (200 msec) thus preventing multiple fixations. This suggests that difference in scanning pattern were not a critical factor in the results. In addition Experiment 14 introduced a secondary task. After judging the shape observers were also reporting on whether the stimulus was perceived as an object or as a hole.

The finding that response time for the hole condition was significantly slower compared to the object condition can be explained by two factors. Firstly processing of additional shape information take place in the hole condition which causes said interference. Secondly, hole stimuli carry a certain amount of ambiguity thus requiring a longer response time. The reasoning behind the second assumption is that closure is a figural factor meaning that in the case of the hole stimuli the closed region is not a figure. Only when the hole is accurately distinguished as a property of another surface, of which the hole is a figural component, can the ambiguity which relates the two be resolved.

In summary, it was reported that inside and outside contours produce an interference effect when they form a single object-with-hole, but not when they form a hierarchical set of surfaces, or a single hole separating different surfaces (a trench). The presence or absence of interference between shapes is determined by the surface that owns the contour.

Overall, localised concavity and convexity coding has been shown to have an impact on the visual perception of shape. A controversy within the related literature has centred on differences in change detection performance between concavity and convexity. It is suggested that the sensitivity to convexity or concavity coding in particular perceptual tasks (such as, visual search displays, change detection task, and judging the stimuli position) is a result of this type of coding having an important role in part parsing (Bertamini, 2001; Hulleman, Winkel, & Boselie, 2000). In relation to differences in detection, Barenholtz, Cohen, Feldman, and Singh (2003) and more specifically Cohen, Barenholtz, Singh, and Feldman (2005) argue that change detection performance in concavities is greater in comparison to change detection in convexities. A corresponding argument states that differences in sensitivity disappears when conditions for convexity and concavity are carefully matched (Bertamini, 2008). It is proposed that the current series of experiments in this thesis present further support for Bertamini's (2008) position. Whilst these findings concur with models of both shape analysis and representations in the brain which make use of concavity and convexity information they do not attribute specific priority to either (Connor, 2004; Suzuki & Cavanagh, 1998; Bell & Gheorghiu, 2009). However, evidence suggests inferotemporal areas do code for convexity; a convexity after-effect that was found is actually present during detection of convexity and concavity (Suzuki, 2003). In relation to the role of closure, evidence suggests that closure may expedite shape processing (Elder & Zucker,

1993) including detection of changes along a contour (Bell, Hancock, Kingdom, & Peirce, 2010). Closure in this case may have acted to create parts that were simple to store information or alternatively it is also possible that closure allowed attention to remain focused upon a smaller region.

This thesis has focused on discussions of 2D concavities and convexities. Therefore the results of this thesis are not in opposition to the strong assumptions of convexity in 3D perception of shape, which is consistent with the numerous neuronal responses to 3D convexity (Langer & Bülthoff, 2001). In terms of ecological validity the assumption of 3D convexity a logical one as exposure to convex objects is more common than concave. Though it should be noted that this does not hold true for convexities and concavities viewed in 2D due to how concave contours are in general projections of saddle regions on a surface, not projections of a concave surface (Koenderink, 1984).

In summary, concavity and convexity are crucial components of both shape analysis and representation, though concavity and convexity do not differ in relation to sensitivity to change.

6.7 Limitation of the current thesis

The experiments conducted as part of this thesis have several limitations. One of the most notable limitations is the complex pattern of results for convexity and concavity. In some cases there is a convexity advantage in detection of symmetry (translation). However, in other cases there was no basic difference between convexity and concavity. Moreover, in the literature, probe discrimination (Barenholtz & Feldman, 2003), positional discrimination (Bertamini & Farrant, 2006) and detection of symmetry tasks (Hulleman & Olivers, 2007) have all been reported to convey advantages for convexity. However, we found that attention is directed automatically to both convexity and concavity equally without any difference in basic sensitivity between them. For example, in the corner enhancement effect, attention is based directly towards the corners and whether this corner is convex or concave has no effect.

Another limitation for the current thesis is that all of our results are from behavioral studies. More evidence from physiological studies is required to support our findings. EEG (Electroencephalography) and fMRI (functional Magnetic Resonance Imaging) studies would be useful in determining areas of the brain which are sensitive to convexity and concavity, for example, the brain area which is sensitive to the corner enhancement effect relative to straight-edges. It would also be interesting to explore which cortical regions show higher sensitivity for convex vertices and concave vertices.

6.8 Implications of the current thesis

The current thesis presents a detailed study of the role of convexity and concavity in perception of shape. This will aid researchers to understand the role of convexity and concavity in perception of shape and shape recognition. For example, in the corner enhancement effect, whether the effect is found for both convex and concave corners is not important. The most important aspect is that the surface that owns the corners determines the effect and that this effect disappears when the probe is near a corner but it is not on the surface that owns the corner. Moreover, in the interference effect the most salient aspect is that the inside and outside of the contour belongs to the same surface.

Another important aspect of this thesis is the demonstration that in some case observers adopt different monitoring strategies. It was shown that participants adopt a strategy when they are confronted with a difficult task in which it is impossible to monitor everything. Researchers would benefit from avoiding making any general or a priori assumptions about sensitivity as participants using a monitoring strategy to perform in the task and this should be considered when reviewing results. An example of this is shown within the work of Hulleman and Oliver (2007).

6.9 Further work

The results of the present thesis indicate that the difference between convexity and concavity in perception of shape is not simple. Consequently, there is much further work to be done. More experiments need to be conducted. For instance, in the corner enhancement effect the series of experiments relied on one task (discrimination between horizontal or vertical probe). We recommend using the corner enhancement effect to respond to other probes. Additionally, more complex objects can be explored, because in the daily human environment a great deal of complicated objects is explored. Consequently, it is logical to extend this set of experiments.

The current thesis used a standard paradigm in the study of visual short-term memory. Although we did not find a difference between the convex and concave conditions, we found that memory for a closed contour was better than for the baseline condition. Hence, many questions remain unanswered about the strategy used by the participants when they store parts in VSTM. Consequently, this closed contour needs to be assessed, for example by monitoring eye tracking to test the difference between closed contour and baseline condition.

An important aspect of the present thesis is the strategy used by the participants. In symmetry experiments, we found that any sign of a convexity advantage disappeared when people did not need to choose which region to monitor. It is possible that a monitoring strategy focusing on the convexities played a role, despite the instructions. This allowed us to conduct and extend further work to test the strategy adopted. What are the components of these strategies? Furthermore, what are the rules that direct these strategies?

A final point to note is that interference was confined to objects-with-holes. However, aspects of the congruence of interference with objects on top of objects are still in need of more investigation to be measured and defined.

6. 10 Conclusions

In summary, there are now clear results illustrating the role of the difference between convexity and concavity in perception of shape in different tasks. The results presented in this thesis explain much about the difference between convexity and concavity implying the salient role of convexity in perception of shape. Future research might be directed at examining the difference between convexity and concavity in perception of shape and the mechanisms and strategies that used to monitor convexity and ignore concavity. To return to the original motivation for this thesis, the importance of convexity and concavity in many perceptual tasks was confirmed in some tasks. There was no basic encoding advantage for convexity over concavity, but we found that the corner enhancement effect exists for both convex and concave corners, and that both convexities and concavities matter for detection of symmetry, and for VSTM.

Reference

Agam, Y., Hyun, J.S., Danker, J.F., Zhou, F., Kahana, M.J., & Sekuler, R. (2009). Early neural signatures of visual short-term memory. *Neuroimage*, 44(2), 531-536.

Albrecht, A.R., List, A., & Robertson, L.C. (2008). Attentional selection and the representation of holes and objects. *Journal of Vision,8* (13),1-10.

Alavsatos, B., & Milner, B. (1989. Effects of frontal or temporal lobectomy on the use of advance information in a choice reaction time task. *Neuropsychologia*, 27(4), 495-503.

Alvarez, G.A., & Cavanagh, P. (2004).The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science, 15*(2), 106-111.

Alvarez, G.A., & Cavanagh, P. (2008). Visual short-term memory operates more efficiently on boundary features than on surface features. *Attention, Perception, & Psychophysics*, *70*(2), 346-364.

Ang, S.Y., & Lee, K. (2010). Exploring developmental differences in visual short-term memory and working memory. *Developmental psychology*, 46(1), 279-285.

Arnott, S.R. & Shedden, J.M. (2000).Attention switching in depth using random-dot autostereograms: Attention gradient asymmetries. *Attention, Perception, & Psychophysics*, 62(7), 1459-1473.

Atchley, P., Kramer, A.F., Andersen, G.J., & Theeuwes, J. (1997). Spatial cuing in a stereoscopic display: Evidence for a "depth-aware" attentional focus. *Psychonomic bulletin & review*, 4(4), 524-529.

Attneave, F. (1954). Some informational aspects of visual perception. *Psychological review*, *61*(3), 183-193.

Avons, S.E., & Phillips, W.A. (1980).Visualization and memorization as a function of display time and poststimulus processing time. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(4), 407-420.

Avons, S.E., & Phillips, W.A. (1987). Representation of matrix patterns in long-and short-term visual memory. *Acta Psychologica*, *65*(3), 227-246.

Awh, E., Barton, B., & Vogel, E.K. (2007). Visual working memory represents a fixed number of items regardless of complexity. *Psychological Science*, *18*(7), 622-628.

Badcock, D.R., & Westheimer, G. (1985). Spatial location and hyperacuity: The centre/surround localization contribution function has two substrates. *Vision Research*, 25(9), 1259-1267.

Baddeley, A.D. (1986) .Working memory. *Oxford, New York.*

Baddeley, A.D. & Hitch, G.J. (1974). Working memory. *The psychology of learning and motivation*, *8*, 47-89.

Barenholtz, E. (2010). Convexities move because they contain matter. *Journal of Vision,10*(11): 19, 1-12.

Barenholtz, E., Cohen, E.H., Feldman, J., & Singh, M. (2003). Detection of change in shape: An advantage for concavities. *Cognition*, *89*(1), 1-9.

Barenholtz, E., & Feldman, J. (2003). Visual comparisons within and between object parts: Evidence for a single-part superiority effect. *Vision Research*, *43*(15), 1655-1666.

Barenholtz, E., & Feldman, J. (2006). Determination of visual figure and ground in dynamically deforming shapes. *Cognition*, *101*(3), 530-544.

Barenholtz, E., & Tarr, M.J. (2009). Figure–ground assignment to a translating contour: A preference for advancing vs. receding motion. *Journal of Vision*, 9(5),1-9 .

Barlow, H.B., & Reeves, B.C. (1979).The versatility and absolute efficiency of detecting mirror symmetry in random dot displays. *Vision Research*, 19(7), 783-793.

Baylis, G.C. (1994). Visual attention and objects: Two-object cost with equal convexity. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(1),208-212.

Baylis, G.C., & Cale, E.M. (2001). The figure has a shape, but the ground does not: Evidence from a planning paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(3), 633-.643.

Baylis, G.C., & Driver Iv, J. (2001). Perception of symmetry and repetition within and across visual shapes: Part-descriptions and object-based attention. *Visual Cognition*, *8*(2), 163-196.

Baylis, G.C., & Driver, J. (1994). Parallel computation of symmetry but not repetition within single visual shapes. *Visual Cognition*, *1*(4), 377-400.

Baylis, G.C. & Driver, J. (1995a). Obligatory edge assignment in vision: The role of figure and part segmentation in symmetry detection. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(6),1323- 1342.

Baylis, G.C., & Driver, J. (1995b). One-sided edge assignment in vision: 1. Figure-ground segmentation and attention to objects. *Current Directions in Psychological Science*, *4*(5), 140-146.

Bell, J. & Gheorghiu, E. (2009). Orientation tuning of curvature adaptation reveals both curvature-polarity-selective and non-selective mechanisms. *Journal of Vision*, 9(12), 1-11.

Bell, J., Hancock, S., Kingdom, F. A. A., & Peirce, J. W. (2010). Global shape processing: Which parts form the whole? *Journal of Vision, 10(6), 1-13.*

Bertamini, M, Friedenberg J., & Kubovy M. (1997). Detection of symmetry and perceptual organization: How a lock-and-key process works. Acta Psychologica, 95, 119-140.

Bertamini, M. (2001). The importance of being convex: An advantage for convexity when judging position. *Perception,30*(11) 1295-1310.

Bertamini, M. (2006). Who owns the contour of a visual hole. *Perception, 35*(7), 883-894.

Bertamini, M. (2008). Detection of convexity and concavity in context. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(4), 775-789.

Bertamini, M. (2010). Sensitivity to reflection and translation is modulated by objectness. *Perception*, *39*(1), 27- 40.

Bertamini, M., & Croucher, C.J. (2003). The shape of holes. *Cognition*, *87*(1), 33-54.

Bertamini, M. & Farrant, T. (2005). Detection of change in shape and its relation to part structure. *Acta Psychologica*, *120*(1), 35-54.

Bertamini, M., Friedenberg, J. & Argyle, L. (2002). No within-object advantage for detection of rotation. *Acta Psychologica*, *111*(1), 59-81.

Bertamini, M., & Lawson, R. (2006).Visual search a circular region perceived as a figure versus as a hole: Evidence of the importance of part structure. *Attention, Perception, & Psychophysics*, *68*(5), 776-791.

Bertamini, M., & Lawson, R. (2008). Rapid figure-ground responses to stereograms reveal an advantage for a convex foreground. *Perception*, *37*(4), 483.

Bertamini, M., & Mosca, F. (2004). Early computation of contour curvature and part structure: Evidence from holes. *Perception*, *33*(1), 35-48.

Beusmans, J.M.H., D.D., & Bennett, B.M. (1987). Description of solid shape and its interference from occluding contour. *Journal of the optical society of America*, 4(7), 1155-1167.

Biederman, I. (1987). Recognition-by-components: a theory of human image understanding, *Psychological review*, 94(2), 115-147.

Bhatt, R.S., Hayden, A., Reed, A., Bertin, E., & Joseph, J. (2006). Infants' perception of information along object boundaries: Concavities versus convexities. *Journal of experimental child psychology*, *94*(2), 91-113.

Borra, S. & Sarkar, S. (1997). A framework for performance characterization of intermediate-level grouping modules, *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 19(11), 1306-1312.

Brady, T.F., Konkle, T., & Alvarez, G.A. (2008). Efficient coding in visual short term memory: Evidence for an information-limited capacity. *Proceeding of 30 Th Annual conference of the cognitive science society (pp.887-892) Austin,Cognitive science socieity.*

Braunstein, M.L., Hoffman, D.D., & Saidpour, A. (1989). Parts of visual objects: An experimental test of the minima rule. *Perception*, *18*(6), 817-826.

Bülthoff, H.H., & Mallot, H.A. (1988). Integration of depth modules: stereo and shading. *Journal of optical scociety of America*, *5*(10).1749-1758.

Burge, J., Peterson, M.A., & Palmer, S.E. (2005). Ordinal configural cues combine with metric disparity in depth perception. *Journal of Vision*, *5*(6),534-542.

Cardaci, M., Millonzi, F., & Tabacchi, M. (2009). Modelling the Effects of Internal Textures on Symmetry Detection Using Fuzzy Operators. *Fuzzy Logic and Applications*, *5571*, 254-262.

Carlson, E.T., Rasquinha, R.J., Zhang, K., & Connor, C.E. (2011). A sparse object coding scheme in area V4. *Current Biology,*21(4),288-293.

Casati, R., & Varzi, A. C., (1994). *Holes and Other Superficialities.* Cambridge, MA: MIT Press.

Cate, A.D., & Behrmann, M. (2010). Perceiving parts and shapes from concave surfaces. *Attention, Perception, & Psychophysics*, *72*(1), 153-167.

Cattaneo, Z., Fantino, M., Silvanto, J., Tinti, C., Pascual-Leone, A., & Vecchi, T. (2010). Symmetry perception in the blind. *Acta Psychologica, 134*(3), 398-402.

Cave, C.B. & Kosslyn, S.M. (1993). The role of parts and spatial relations in object identification. *Perception*, 22, 229-248.

Cohen, E.H., Barenholtz, E., Singh, M., & Feldman, J. (2005). What change detection tells us about the visual representation of shape. *Journal of Vision*, *5(*4),313-321.

Cohen, E.H., & Singh, M. (2006). Perceived orientation of complex shape reflects graded part decomposition. *Journal of Vision*, *6*(8),805-821.

Cohen, E.H., & Singh, M. (2007). Geometric determinants of shape segmentation: Tests using segment identification. *Vision Research*, *47*(22), 2825-2840.

Cohen, J.D., Perlstein, W.M., Braver, T.S., Nystrom, L.E., Noll, D.C., Jonides, J., & Smith, E.E. (1997). Temporal dynamics of brain activation during a working memory task, *604-608*.

Cole, G., Gellatly, A., & Blurton, A. (2001). Effect of object onset on the distribution of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(6), 1356-1368.

Cole, G.G., Kentridge, R.W., & Heywood, C.A. (2004). Visual salience in the change detection paradigm: the special role of object onset. *Journal of Experimental Psychology: Human Perception and Performance, 30*(3), 464-477.

Cole, G.G., Skarratt, P.A., & Gellatly, A.R.H. (2007). Object and spatial representations in the corner enhancement effect. *Attention, Perception, & Psychophysics*, *69*(3),400-412.

Connor, C.E.(2004). Shape dimensions and object. The visual neuroscience. London: MIT Press, (pp. 1080–1089).

Corballis, M.C., & Roldan, C.E. (1974). On the perception of symmetrical and repeated patterns. *Attention, Perception, & Psychophysics*, *16*(1), 136-142.

Courtney, S.M., Ungerleider, L.G., Keil, K., & Haxby, J.V. (1996). Object and spatial visual working memory activate separate neural systems in human cortex, *Cerebral Cortex*, 6(1), 39-49.

Cowan, N. (1998). Visual and auditory working memory capacity. *Trends in Cognitive Sciences*, *2*(3), 77-80.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and brain sciences*, *24*(1), 87-114.

Cowan, N., Elliott, E.M., Scott Saults, J., Morey, C.C., Mattox, S., Hismjatullina, A., & Conway, A.R.A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive psychology*, *51*(1), 42-100.

Csathó, Á., van der Vloed, G., & van der Helm, P.A. (2003). Blobs strengthen repetition but weaken symmetry. *Vision Research*, *43*(9), 993-1007.

Curby, K.M., & Gauthier, I. (2007). A visual short-term memory advantage for faces. *Psychonomic bulletin & review*, *14*(4), 620-628.

Curby, K.M., Glazek, K., & Gauthier, I. (2009). A visual short-term memory advantage for objects of expertise. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(1), 94-107.

Dakin, S.C., & Watt, R.J. (1994). Detection of bilateral symmetry using spatial filters. *Spatial Vision*, *8*(4)393-413.

Davis, G., & Holmes, A. (2005). The capacity of visual short-term memory is not a fixed number of objects. *Memory & cognition*, *33*(2), 185-195.

De Winter, J., & Wagemans, J. (2008). The awakening of Attneave's sleeping cat: Identification of everyday objects on the basis of straight-line versions of outlines. *Perception*, 37(2), 245.

Delvenne, J.F. (2005). The capacity of visual short term memory within and between hemi fields. *Cognition*, *96*, 79-88.

Delvenne, J.F., & Bruyer, R. (2004). Does visual short-term memory store bound features? *Visual Cognition*, 11(1), 1-27.

Delvenne, J.F., Cleeremans, A., & Laloyaux, C. (2010). Feature bindings are maintained in visual short-term memory without sustained focused attention. *Experimental Psychology (formerly Zeitschrift für Experimentelle Psychologie)*, *57*(2), 108-116.

Dobbins, A., Zucker, S.W., & Cynader, M.S. (1989). Endstopping and curvature. *Vision Research*, *29*(10), 1371-1387.

Doyon, J., & Milner, B. (1991). Right temporal-lobe contribution to global visual processing. *Neuropsychologia*, 29(5), 343-360.

Driver, J., & Baylis, G.C. (1995). One-Sided Edge Assignment in Vision: 2. Part Decomposition, Shape Description, and Attention to Objects. *Current Directions in Psychological Science*, *4*(6), 201-206.

Driver, J., Baylis, G.C., & Rafal, R.D. (1992). Preserved figure-ground segregation and symmetry perception in visual neglect. *Nature*, *360*(6399), 73-75.

Elder, J., & Zucker, S. (1993). The effect of contour closure on the rapid discrimination of two-dimensional shapes. *Vision Research*, 33(7), 981-991.

Elliott, R., & Dolan, R.J. (1998). The neural response in short-term visual recognition memory for perceptual conjunctions. *Neuroimage*, *7*(1), 14-22.

Eng, H.Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex visual stimuli. *Psychonomic bulletin & review*, *12*(6), 1127-1133.

Enns, J.T., & Rensink, R.A. (1990). Sensitivity to three-dimensional orientation in visual search. *Psychological Science*,1(5), 323-326.

Eriksen, C.W., & Schultz, D.W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Attention, Perception, & Psychophysics*, 25(4), 249-263.

Fantoni, C., Bertamini, M., & Gerbino, W. (2005). Contour curvature polarity and surface interpolation. *Vision Research*, 45(8). 1047-1062.

Feldman, J., & Singh, M. (2005). Information along contours and object boundaries. *Psychological review*, *112*(1), 243-252.

Fougnie, D., & Marois, R. (2006). Distinct capacity limits for attention and working memory. *Psychological Science*, *17*(6), 526-534.

Fougnie, D., & Marois, R. (2009). Dual-task interference in visual working memory: A limitation in storage capacity but not in encoding or retrieval. *Attention, Perception, & Psychophysics*, *71*(8), 1831-1841.

Freyd, J., & Tversky, B. (1984). Force of symmetry in form perception. *The American journal of psychology*,97(1), 109-126.

Friedenberg, J., & Bertamini, M. (2000). Contour symmetry detection: The influence of axis orientation and number of objects. *Acta Psychologica*, *105*(1), 107-118.

Gellatly, A., & Cole, G. (2000). Accuracy of target detection in new-object and old-object displays. *Journal of Experimental Psychology: Human Perception and Performance*, *26(*3), 889-899.

Gellatly, A., Cole, G., & Blurton, A. (1999). Do equiluminant object onsets capture visual attention? *Journal of Experimental Psychology: Human Perception and Performance*, *25*(6), 1609-1624

Gibson, B.S. (1994). Visual attention and objects: One versus two or convex versus concave. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(1), 203-207.

Gillam, B.J., & Cook, M.L. (2001). Perspective based on stereopsis and occlusion. *Psychological Science*, *12*(5), 424.

Giurfa, M., Eichmann, B., & Menzel, R. (1996). Symmetry perception in an insect. *Nature*, 382(6590), 458-461.

Gratton, G., Coles, M.G., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*(4), 480-506.

Habak, C., Wilkinson, F., Zakher, B., & Wilson, H.R. (2004). Curvature population coding for complex shapes in human vision. *Vision Research*, *44*(24), 2815-2823.

Harris, J.M., & Wilcox, L.M. (2009). The role of monocularly visible regions in depth and surface perception. *Vision Research*, *49*(22), 2666-2685.

Haushofer, J., Baker, C.I., Livingstone, M.S., & Kanwisher, N. (2008). Privileged coding of convex shapes in human object-selective cortex. *Journal of neurophysiology*, 100(2), 753-762.

Hayden, A., Bhatt, R.S., Kangas, A., & Zieber, N. (2011). Parts, cavities, and object representation in infancy. *Journal of Experimental Psychology: Human Perception and Performance, 37*(1), 314-317.

Hebb, D. O. (1949). The organization of behavior: A neuropsychological theory. New York: Wiley.

Hess, R.F., Wang, Y.Z., & Dakin, S.C. (1999). Are judgements of circularity local or global? . *Vision Research,* 39(26), 4354-4360.

Hoffman, D.D. (2000). *Visual intelligence: How we create what we see*, WW Norton Company.

Hoffman, D.D., & Richards, W.A. (1984).Parts of recognition. *Cognition*,18(1), 65-96.

Hoffman, D.D., & Singh, M. (1997). Salience of visual parts. *Cognition*, *63*(1), 29-78.

Horowitz, T.S., & Kuzmova, Y. (2011). Can we track holes. *Vision Research, 51(*9), 1013-1021.

Horridge, G.A. (1996). The honeybee (Apis mellifera) detects bilateral symmetry and discriminates its axis. *Journal of Insect Physiology*, *42*(8), 755-764.

Howard, I. (1983). Occluding edges in apparent reversal of convexity and concavity. *Perception, 12*(1), 85-86.

Howard, I.P., & Templeton, W.B. (1966). Human spatial orientation. Oxford, England: John Wiley & Sons. p 533.

Huang, L., Pashler, H., & Junge, J.A. (2004). Are there capacity limitations in symmetry perception. *Psychonomic bulletin & review, 11*(5), 862-869.

Hulleman, J., & Humphreys, G.W. (2004a). Is there an assignment of top and bottom during symmetry perception. *Perception, 33,* 615-620.

Hulleman, J., & Humphreys, G.W. (2004b). A new cue to figure-ground coding: Top-bottom polarity. *Vision Research*, *44*(24), 2779-2791.

Hulleman, J., & Humphreys, G.W. (2005). Differences between searching among objects and searching among holes. *Attention, Perception, & Psychophysics*, *67*(3), 469-482.

Hulleman, J., & Olivers, C.N.L. (2007). Concavities count for less in symmetry perception. *Psychonomic bulletin & review*, *14*(6), 1212-1217.

Hulleman, J., Winkel, W., & Boselie, F. (2000). Concavities as basic features in visual search: Evidence from search asymmetries. *Attention, Perception, & Psychophysics*, *62*(1), 162-174.

Humphreys, G.W. (1999). Integrative agnosia. In G.W. Humphreys (Ed.), Case studies in the neuropsychology of vision (pp. 41–58). London: Psychology Press.

Humphreys, G.W., & Müller, H. (2000) . A search asymmetry reversed by figure-ground assignment. *Psychological Science*, *11*(3), 196-201.

Jacobs, D.W. (1996). Robust and efficient detection of salient convex groups. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *18*(1), 23-37.

Jiang, Y., Chun, M.M., & Olson, I.R. (2004). Perceptual grouping in change detection. *Attention, Perception, & Psychophysics*, *66*(3), 446-453.

Jiang, Y., Olson, I.R., & Chun, M.M. (2000). Organization of visual short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(3), 683-702.

Jiang, Y.V., Makovski, T., Shim, W.M., & Brockmole, J.R. (2009). Visual memory for features, conjunctions, objects, and locations. *The visual world in memory*, 33-65.

Johnson, J.S., Hollingworth, A., & Luck, S.J. (2008). The role of attention in the maintenance of feature bindings in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(1), 41-55.

Julesz, B. (1971). Foundations of cyclopean perception. Oxford, England: U. Chicago Press, P.406

Kanizsa, G., & Gerbino, W. (1976). Convexity and symmetry in figure-ground organization. *Vision and artifact*, 25-32.

Kim, J.H., & Peterson, M.A. (2001) .Context modulates the strength of Gestalt configural cue of convexity. *Journal of Vision*, *1*(3), 390.

Kimchi, R. & Peterson, M.A. (2008). Figure-ground segmentation can occur without attention. *Psychological Science*, *19*(7), 660-668.

Klymenko, V., & Weisstein, N. (1986). Spatial frequency differences can determine figure-ground organization. *Journal of Experimental Psychology: Human Perception and Performance*, *12*(3), 324- 330.

Ko, P.C., & Seiffert, A.E. (2009). Updating objects in visual short-term memory is feature selective. *Memory & cognition*, *37*(6), 909-923.

Koenderink, J.J. (1984). What does the occluding contour tell us about solid shape. *Perception*, *13*(3), 321-330.

Koenderink J.J. (1990) *Solid shape*. MIT Press, Cambridge, Massachusetts.

Koenderink, J.J., & Van Doorn, A.J. (1982). The shape of smooth objects and the way contours end. *Perception*, *11*(2), 129-137.

Koffka, K., (1935). *Principles of Gestalt Psychology*. New York: Harcourt Brace.

Koning, A., & van Lier, R. (2006). No symmetry advantage when object matching involves accidental viewpoints. *Psychological research*, *70*(1), 52-58.

Koning, A., & Wagemans, J. (2009). Detection of Symmetry and Repetition in One and Two Objects. *Experimental Psychology (formerly Zeitschrift für Experimentelle Psychologie)*, *56*(1), 5-17.

Kovacs, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure-ground segmentation. *Proceedings of the National Academy of Sciences*, 90(16), 7495-7497.

Kristjánsson, Á., & Tse, P.U. (2001). Curvature discontinuities are cues for rapid shape analysis. *Attention, Perception, & Psychophysics*, *63*(3), 390-403.

Kröse, B.J.A., & Julesz, B. (1989). The control and speed of shifts of attention. *Vision Research*, 29(11), 1607-1619.

Kumar, A., & Jiang, Y. (2005). Visual short-term memory for sequential arrays. *Memory & cognition*, *33*(3), 488-498.

Lamme, V. A. F., Zipser, K., & Spekreijse, H. (2002). Masking interrupts figure-ground signals in V1. *Journal of Cognitive Neuroscience, 14(7)*, 1044-1053.

Lamote, C., & Wagemans, J. (1999). Rapid integration of contour fragments: from simple filling-in to parts-based shape description. *Visual Cognition*, *6*(3-4), 345-361.

Langer, M.S., & Bulthoff, H.H. (2001). A prior for global convexity in local shape-from shading. *Perception*, 30(4),403-410.

Latecki, L.J., & Lakämper, R. (1999). Convexity rule for shape decomposition based on discrete contour evolution. *Computer Vision and Image Understanding*, *73*(3), 441-454.

Lazareva, O.F., Castro, L., Vecera, S.P., & Wasserman, E.A. (2006. Figure-ground assignment in pigeons: Evidence for a figural benefit. *Attention, Perception, & Psychophysics*, 68(5), 711-724.

Lee, D., & Chun, M.M. (2001). What are the units of visual short-term memory, objects or spatial locations. *Attention, Perception, & Psychophysics*, *63*(2), 253-257.

Lisman, J.E., & Idiart, M.A. (1995). Storage of 7+/-2 short-term memories in oscillatory subcycles. *Science*, *267*(5203), 1512-1515.

Liu, Z., Jacobs, D.W., & Basri, R. (1999). The role of convexity in perceptual completion: Beyond good continuation. *Vision Research*, *39*(25), 4244-4257.

Logie, R.H. (1989). Characteristics of visual short-term memory. *European Journal of Cognitive Psychology*, *1* (4), 275-284.

Logie, R.H., Zucco, G.M., & Baddeley, A.D. (1990). Interference with visual short-term memory. *Acta Psychologica*, *75*(1), 55-74.

Luck, S.J., & Hollingworth, A.R. (2008). *Visual memory*, Oxford University Press, USA.

Luck, S.J., & Vogel, E.K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279-281.

Machilsen, B., Pauwels, M., & Wagemans, J. (2009). The role of vertical mirror symmetry in visual shape detection. *Journal of Vision*, 9(12):11, 1-11.

Macmillan, N.A., & Creelman, C.D. (2005) *Detection theory: A user's guide*, Lawrence Erlbaum.

Masame, K. (1984). Detection of symmetry in relatively simple patterns. *Tohoku Psychologica Folia*, *43*(1-4), 42-48.

Makovski, T., & Jiang, Y.V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychonomic bulletin & review*, *14*(6), 1072-1078.

Makovski, T., & Jiang, Y.V. (2008). Indirect assessment of visual working memory for simple and complex objects. *Memory & cognition*, *36*(6), 1132-1143.

Mathes, B. & Fahle, M. (2007). Closure facilitates contour integration. *Vision Research*, *47*(6), 818-827.

Mazza, V., Turatto, M., & Umilta, C. (2005). Foreground–background segmentation and attention: A change blindness study. *Psychological research*, 69(3), 201-210.

McCollough, A.W., Machizawa, M.G., & Vogel, E.K. (2007). Special issue: Original article electrophysiological measuers of maintaning representaion in visual working memory.*Cortex*, *43*, 77-94.

Mitchell, D.J., & Cusack, R. (2008). Flexible, capacity-limited activity of posterior parietal cortex in perceptual as well as visual short-term memory tasks. *Cerebral Cortex*, *18*(8), 1788-1789.

Moore, C.D., Cohen, M.X., & Ranganath, C. (2006. Neural mechanisms of expert skills in visual working memory. *The Journal of Neuroscience*, 26(43), 11187-11196.

Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Research*, 29(11), 1631-1647.

Nakayama, K., Shimojo, S., & Silverman, G. H. (1989). Stereoscopic depth: its relation to image segmentation, grouping, and the recognition of occluded objects. *Perception*, *18*, 55–68.

Nelson, R., & Palmer, S.E. (2001). Of holes and wholes: The perception of surrounded regions. *Perception*, *30*(10), 1213-1226.

Nelson, R., Thierman, J., & Palmer, S.E. (2009). Shape memory for intrinsic versus accidental holes. *Attention, Perception, & Psychophysics*, *71*(1), 200-206.

Nelson, R.A., & Palmer, S.E. (2007). Familiar shapes attract attention in figure-ground displays. *Attention, Perception, & Psychophysics*, *69*(3), 382-392.

Nickerson, R.S. (1965). Short-term memory for complex meaningful visual configurations: A demonstration of capacity. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *19*(2), p. 155-160.

Norman, J.F., Phillips, F., & Ross, H.E. (2001). Information concentration along the boundary contours of naturally shaped solid objects. *Perception*, 30(11), 1285-1294.

Oakes, L.M., Ross-Sheehy, S., & Luck, S.J. (2006). Rapid development of feature binding in visual short-term memory. *Psychological Science*, *17*(9), 781-787.

Offen, S., Schluppeck, D., & Heeger, D.J. (2009). The role of early visual cortex in visual short-term memory and visual attention. *Vision Research, 49*(10), 1352-1362.

Olson, I.R., & Jiang, Y. (2002). Is visual short-term memory object based? Rejection of the "strong-object" hypothesis. *Attention, Perception, & Psychophysics, 64*(7), 1055-1067.

Olson, I.R., & Jiang, Y. (2004). Visual short-term memory is not improved by training. *Memory & cognition*, *32*(8), 1326-1332.

Olsson, H., & Poom, L. (2005). Visual memory needs categories. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(24), 8776-8780.

Palmer, S., Davis, J., Nelson, R., & Rock, I. (2008). Figure–ground effects on shape memory for objects versus holes. *Perception*, 37(10), 1569-1586.

Palmer, S.E., & Hemenway, K. (1978). Orientation and symmetry: effects of multiple, rotational, and near symmetries. *Journal of Experimental Psychology: Human Perception and Performance,* 4(4), 691-702.

Palmer, S., & Ghose, T. (2008). External edges: A powerful cue to depth perception and figure ground organization. *Psychological science, 19*(1), 77-84.

Pao, H.K., Geiger, D., & Rubin, N. (1999). Measuring convexity for figure/ground separation, *2*(942), IEEE, 948-955.

Pashler, H. (1988). Familiarity and visual change detection. *Attention, Perception, & Psychophysics*, *44*(4), 369-378.

Pasupathy, A., & Connor, C.E. (2001). Shape representation in area V4: position-specific tuning for boundary conformation. *Journal of neurophysiology*, 86(5), 2505-2519.

Pessoa, L., Gutierrez, E., Bandettini, P.A., & Ungerleider, L.G. (2002). Neural correlates of visual working memory: fMRI amplitude predicts task performance. *Neuron*, 35(5), 975-987.

Peterson, M., & Salvagio, E. (2010) . Figure-ground perception. *Scholarpedia*, 5(4), 4320. doi:10.4249/scholarpedia.4320.

Peterson, M.A., & Gibson, B.S. (1994a). Must figure-ground organization precede object recognition? An assumption in peril. *Psychological Science,* 5(5), 253-259.

Peterson, M.A., & Gibson, B.S. (1994b). Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours. *Attention, Perception, & Psychophysics*, *56*(5), 551-564.

Peterson, M.A., & Kim, J.H. (2001). On what is bound in figures and grounds. *Visual Cognition*, *8*(3-5), 329-348.

Peterson, M.A., & Lampignano, D.W. (2003). Implicit memory for novel figure-ground displays includes a history of cross-border competition. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(4), 808-828.

Peterson, M.A., & Skow, E. (2008). Inhibitory competition between shape properties in figure-ground perception. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(2), 251-267.

Peterson, M. A., & Skow-Grant, E. (2003). Memory and learning in figure-ground perception. In B. Ross & D. Irwin (Eds.) *Cognitive Vision: Psychology of Learning and Motivation* (pp. 1-34). Academic Press.

Phillips, W.A. (1974). On the distinction between sensory storage and short-term visual memory. *Attention, Perception, & Psychophysics*, *16*(2), 283-290.

Pickering, S.J. (2001). Cognitive approaches to the fractionation of visuo-spatial working memory. Cortex, 37, 457-473.

Pigott, S., & Milner, B. (1994). Capacity of visual short-term memory after unilateral frontal or anterior temporal-lobe resection. *Neuropsychologia*, *32*(8), 969-981.

Pinna, B., Werner, J.S., & Spillmann, L. (2003). The watercolor effect: a new principle of grouping and figure-ground organization. *Vision Research*, 43(1), 43-52.

Poirier, F.J.A.M., & Wilson, H.R. (2007). Object perception and masking: Contributions of sides and convexities. *Vision Research*, 47(23),3001-3011.

Postle, B.R., Awh, E., Jonides, J., Smith, E.E., & D'Esposito, M. (2004). The where and how of attention-based rehearsal in spatial working memory. *Cognitive Brain Research*, 20(2),. 194-205.

Pylyshyn, Z.W., & Storm, R.W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism, *Spatial Vision*, 3(3), 179-197.

Rensink, R.A. (2002). Change detection. *Annual review of psychology*, 53(1), 245-277. Riggs, K.J., McTaggart, J., Simpson, A., & Freeman, R.P.J. (2006). Changes in the capacity of visual working memory in 5-to 10-year-olds. *Journal of experimental child psychology*, *95*(1), 18-26.

Riggs, K.J., McTaggart, J., Simpson, A., & Freeman, R.P.J. (2006). Changes in the capacity of visual working memory in 5-to 10-year-olds. *Journal of experimental child psychology*, 95(1), 18-26.

Rose, S.A., Feldman, J.F., & Jankowski, J.J. (2001). Visual short-term memory in the first year of life: Capacity and recency effects. *Developmental psychology*, 37(4), 539-549.

Rosin, P.L. (2000). Shape partitioning by convexity. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, *30*(2), 202-210.

Ross-sheehy, S., Oakes, L.M., & Luck, S.J. (2003). The development of visual short-term memory capacity in infants. *Child Development*, *74*(6), 1807-1822.

Rouder, J.N., Morey, R.D., Cowan, N., Zwilling, C.E., Morey, C.C., & Pratte, M.S. (2008). An assessment of fixed-capacity models of visual working memory. *Proceedings of the National Academy of Sciences*, 105(16), 5975-5979.

Royer, F.L. (1981). Detection of symmetry. *Journal of Experimental Psychology: Human Perception and Performance*, 7(6), 1186- 1210.

Rubin, E. (1921). *Visuell wahrgenommene figuren*. Kobenhaven: Glydenalske boghandel.

Rubin (1958). igure-Ground Perception In: Readings in perception , *Translated from German by M. Wertheimer. Princeton, NJ: Van Nostrand. pp 194-203 (Original work published 1915).*

Saiki, J., & Hummel, J.E. (1998). Connectedness and the integration of parts with relations in shape perception. *Journal of Experimental Psychology: Human Perception and Performance*, 24(1), 227-251.

Saiki, J., & Miyatsuji, H. (2009). Estimated capacity of object files in visual short-term memory is not improved by retrieval cueing. *Journal of Vision*, *9*(3):16,1-15.

Sakai, K., & Inui, T. (2002). A feature-segmentation model of short-term visual memory. *Perception*, *31*(5), 579-590.

Saults, J.S., & Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and auditory arrays in working memory. *Journal of Experimental Psychology: General*, *136*(4), 663-684.

Sauseng, P., Klimesch, W., Heise, K.F., Gruber, W.R., Holz, E., Karim, A.A., Glennon, M., Gerloff, C., Birbaumer, N., & Hummel, F.C. (2009). Brain oscillatory substrates of visual short-term memory capacity. *Current Biology, 19*(21), 1846-1852.

Sawada, T., & Pizlo, Z. (2008). Detection of skewed symmetry. *Journal of Vision*, 8(5), 1-18.

Schmidt, B.K., Vogel, E.K., Woodman, G.F., & Luck, S.J. (2002). Voluntary and automatic attentional control of visual working memory. *Attention, Perception, & Psychophysics*, 64(5), 754-763.

Scholl, B.J., & Pylyshyn, Z.W. (1999). Tracking multiple items through occlusion: Clues to visual objecthood. *Cognitive psychology*, 38(2), 259-290.

Schweickert, R., & Boruff, B. (1986). Short-term memory capacity: Magic number or magic spell?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 12(3), 419-425.

Simons, D.J., & Rensink, R.A. (2005). Change blindness: Past, present, and future, *Trends in Cognitive Sciences*, 9(1), 16-20.

Singh, M. & Hoffman, D.D. (1998). Part boundaries alter the perception of transparency. *Psychological Science*, 9(5), 370-378.

Singh, M., & Hoffman, D.D. (2001). 13 Part-based representations of visual shape and implications for visual cognition. *Advances in psychology*, 130, 401-459.

Singh, M., Seyranian, G.D., & Hoffman, D.D. (1999). Parsing silhouettes: The short-cut rule. *Attention, Perception, & Psychophysics*, *61*(4), 636-660.

Song, J.H., & Jiang, Y. (2006). Visual working memory for simple and complex features: An fMRI study. *Neuroimage*, *30*,(3), 963-972.

Stefurak, D.L., & Boynton, R.M. (1986). Independence of memory for categorically different colors and shapes. *Attention, Perception, & Psychophysics*, *39*(3), 164-174.

Stevens, K.A., & Brookes, A. (1988). The concave cusp as a determiner of figure-ground. *Perception*, *17*(1), 35-42.

Stins, J. F., Polderman, J. C. T., Boomsma, D. I., & de Geus, E. J. C. (2007). Conditional accuracy in response interference tasks: Evidence from the Eriksen flanker task and the spatial conflict task. *Advances in cognitive psychology*, *3,* 389-396.

Suzuki, S. (2003). Attentional selection of overlapped shapes: A study using brief shape aftereffects. *Vision Research*, 43(5), 549-561.

Suzuki, S., & Cavanagh, P. (1998). A shape- contrast effect for briefly presented stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, 24(5), 1-27.

Tek, H., & Kimia, B. (1995). Image Segmentation by Reaction-Diffusion Bubbles. In *International Conference of Computer Vision*,156-162.

Todd, J.J., & Marois, R. (2004). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature*, *428* (6984), 751-754.

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychological Review*, 95(1), 15-48.

Tyler, C.W. (1995). Empirical aspects of symmetry perception. *Spatial Vision*, 9(1), 1-8.

van der Helm, P.A. (2010) . Weber-Fechner behavior in symmetry perception? *Attention, Perception, & Psychophysics*, *72*(7), 1854-1864.

van der Helm, P.A., & Leeuwenberg, E.L.J. (1996). Goodness of visual regularities: A nontransformational approach. *Psychological Review*, 103(3), 429-456.

van der Helm, P.A., & Treder, M.S. (2009). Detection of (anti) symmetry and (anti) repetition: Perceptual mechanisms versus cognitive strategies. *Vision Research*, *49*(23), 2754-2763.

van der Vloed, G., Csathó, Á., & van der Helm, P.A. (2005). Symmetry and repetition in perspective. *Acta Psychologica*, *120*(1), 74-92.

van Lier, R., & Wagemans, J. (1998). Effects of physical connectivity on the representational unity of multi-part configurations, *Cognition*, 69(1), B1-B9.

Vandekerckhove, J., Panis, S., & Wagemans, J. (2007). The concavity effect is a compound of local and global effects. *Attention, Perception, & Psychophysics*, *69*(7), 1253-1260.

Vecera, S.P., Behrmann, M., & McGoldrick, J. (2000). Selective attention to the parts of an object. *Psychonomic bulletin & review*, *7*(2), 301-308.

Vecera, S.P., & Farah, M.J. (1994). Does visual attention select objects or locations?. *Journal of Experimental Psychology: General*, 123(2), 146-160.

Vecera, S.P., Flevaris, A.V., & Filapek, J.C. (2004). Exogenous spatial attention influences figure-ground assignment. *Psychological Science*, 15(1), 20-26.

Vecera, S.P., & Palmer, S.E. (2006). Grounding the figure: Surface attachment influences figure-ground organization. *Psychonomic bulletin & review*, *13*,(4), 563-569.

Vecera, S.P., Vogel, E.K., & Woodman, G.F. (2002). Lower region: A new cue for figure-ground assignment. *Journal of Experimental Psychology: General*, *131*(2), 194-205.

Vinberg, J., & Grill-Spector, K. (2008). Representation of shapes, edges, and surfaces across multiple cues in the human visual cortex. *Journal of neurophysiology*, 99(3), 1380-1393.

Vogel, E.K., & Machizawa, M.G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*(6984), 748-751.

Vogel, E.K., Woodman, G.F., & Luck, S.J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 27(1), 92-114.

Vogel, E.K., Woodman, G.F., & Luck, S.J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 32(6), 1436-1451.

Vuong, Q.C., Domini, F., & Caudek, C. (2006). Disparity and shading cues cooperate for surface interpolation. *Perception*, *35*, 145-155.

Wagemans, J. (1995). Detection of visual symmetries. *Spatial Vision*, *9*(1), 9-32.

Wagemans, J. (1997). Characteristics and models of human symmetry detection. *Trends in Cognitive Sciences*, *1*(9), 346-352.

Wagemans, J., Van Gool, L., & d'Ydewalle, G. (1992). Orientational effects and component processes in symmetry detection. *The Quarterly Journal of Experimental Psychology*, *44*(3), 475-508.

Walker, P., Hitch, G.J., & Duroe, S. (1993). The effect of visual similarity on short-term memory for spatial location: Implications for the capacity of visual short-term memory. *Acta Psychologica*, *83*(3), 203-224.

Wang, S., Stahl, J.S., Bailey, A., & Dropps, M. (2007). Global detection of salient convex boundaries. *International Journal of Computer Vision*, *71*(3), 337-359.

Wenderoth, P. (1994). The salience of vertical symmetry. *Perception*, *23*, 221-221.

Wheeler, M.E., & Treisman, A.M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, 131(1), 48-64.

Wilken, P., & Ma, W.J. (2004). A detection theory account of change detection. *Journal of Vision*, 4(12),1120-1135. Wilson, J.T., Scott, J.H. & Power, K.G. (1987). Developmental differences in the span of visual memory for pattern , *British Journal of Developmental Psychology*, 5(3), 249-255.

Wolfe, J.M. & Bennett, S.C. (1997). Preattentive object files: Shapeless bundles of basic features. *Vision Research*, 37(1), 25-43.

Wolfe, J.M., Yee, A. & Friedman-Hill, S.R. (1992). Curvature is a basic feature for visual search tasks. *Perception*, *21*, 465-465.

Wong, E. & Weisstein, N. (1982). A new perceptual context-superiority effect: Line segments are more visible against a figure than against a ground. *Science, 218(4572)*, 587-589.

Woodman, G.F., Vecera, S.P. & Luck, S.J. (2003). Perceptual organization influences visual working memory, *Psychonomic bulletin & review*, 10(1), 80-87.

Woodman, G.F. & Vogel, E.K. (2008). Selective storage and maintenance of an object's features in visual working memory. *Psychonomic bulletin & review*, *15*(1), 223-229.

Xu, Y. (2002a). Encoding color and shape from different parts of an object in visual short-term memory. *Attention, Perception, & Psychophysics*, *64*(8), 1260-1280.

Xu, Y. (2002b). Limitations of object-based feature encoding in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(2),. 458-468.

Xu, Y. (2006). Understanding the object benefit in visual short-term memory: The roles of feature proximity and connectedness. *Attention, Perception, & Psychophysics*, *68*
(5), 815-828.

Xu, Y. (2007). The role of the superior intraparietal sulcus in supporting visual short-term memory for multifeature objects. *The Journal of Neuroscience*, 27(43),11676-11686.

Xu, Y. & Chun, M.M. (2006). Dissociable neural mechanisms supporting visual short-term memory for objects. *Nature*, *440*(7080), 91-95.

Xu, Y. & Nakayama, K. (2007). Visual short-term memory benefit for objects on different 3-D surfaces. *Journal of Experimental Psychology: General*, 136(4), 653.

Xu, Y. & Singh, M. (2002). Early computation of part structure: Evidence from visual search. *Attention, Perception, & Psychophysics*, 64(7), 1039-1054.

Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *19*(3),676-681.

Zhang, W. & Luck, S.J. (2008). Discrete fixed-resolution representations in visual working memory. *Nature*, 453(7192), 233-235.

Zhou, H., Friedman, H.S. & Von Der Heydt, R. (2000). Coding of border ownership in monkey visual corte.*The Journal of Neuroscience*, 20(17), 6594-6611.

Appendix 1

CONSENT FORM

Title of Research Perception and cognition

Researcher(s): Mai Helmy

Please initial box

1. I confirm that I have read and have understood the information sheet dated [DATE] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. ☐

3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ☐

4. I agree to take part in the above study. ☐

______________________	________	______________
Participant Name	Date	Signature
______________________	________	______________
Name of Person taking consent	Date	Signature
______________________	________	______________
Researcher	Date	Signature

The contact details of lead Researcher (Principal Investigator) are:

Mai Salah Helmy	Maisalah@liverpool.ac.uk
School of Psychology	+44 (0)151 794 2954 (office)
Eleanor Rathbone Building	
University of Liverpool	http://www.liv.ac.uk/VP/
Liverpool L69 7 ZA	