INVESTIGATING THE ROLE OF POSITION AND ORIENTATION IN SHAPE PERCEPTION USING VISUAL CROWDING AND CONTOUR INTEGRATION

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BY

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PLAGIARISM

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ABSTRACT

The deterioration or reduction of the perception of the target due to the nearby objects is called the visual crowding effect. Crowding can occur as a result of similarity and proximity. These two conditions also result in contour perception with high congruency between the elements. Contour perception is the unitary perception of congruent individual items. Although many physical aspects can result in crowding and contour perception, congruencies of orientation and position are the two primary indicators. In this experiment, four positional configurations, namely left-circle, right-circle, left-diagonal and right-diagonal, of the target and flankers were used. According to these positional configurations, congruent and incongruent orientations were created. We hypothesized that crowding and contour should have an exhibitory effect on each other. In the previous studies, target and contour objects were separated from each other. In this study, the target was also a part of the contour pattern. This allowed us to observe the interaction of crowding and contour in the same arrangement. The task was a simple orientation discrimination task between two targets. Another hypothesis was that low-level shapes' contour perception should occur even with three objects in the scene. The accuracy rates (percentage) and reaction times (ms) were compared as outcome variables. The results indicated that contour and crowding are two concepts that cannot co-exist based on the accuracy results. Also, the analysis of the accuracy rates confirmed that the three objects were enough to create simple linear shapes but not circular shapes.

Keywords: contour integration, visual crowding, positional configuration, visual grouping

ÖZET

Yakındaki cisimler nedeniyle hedefin algısının bozulması veya azalmasına görsel "crowding" etkisi denir. Crowding, benzerlik ve yakınlığın bir sonucu olarak ortaya çıkabilir. Bu iki koşul aynı zamanda objeler arasında yüksek uyumluluğun sonucunda oluşabilecek "contour" (şekil) algısı ile sonuçlanır. Contour algısı, uyumlu bireysel öğelerin bir bütünmüş gibi algılanmasına denir. Birçok fiziksel özellik, crowding ve contour algısı ile sonuçlanabilse de, oryantasyon ve konum uyumları iki ana göstergedir. Bu deneyde, hedef ve crowding yapan cisimlerin sol-daire, sağ-daire, sol-çapraz ve sağ-çapraz olmak üzere dört konum konfigürasyonu kullanılmıştır. Bu konumsal konfigürasyonlara göre uyumlu ve uyumsuz açılar oluşturulmuştur. Kalabalık ve konturun birbiri üzerinde arttırıcı bir etkisi olması gerektiğini hipotezini kurduk. Daha önceki çalışmalarda hedef ve contour nesneleri birbirinden ayrı tutularak deney –ler yapılmıştı. Bu çalışmada hedef aynı zamanda contor düzeninin bir parçasıydı. Bu, aynı düzende crowding ve contour etkileşimini gözlemlememizi sağladı. Katılımcıların görevi, iki hedef arasındaki eğimi ayırt etmekti. Diğer bir hipotez, basit şekillerin contour algısının, görüş alanındaki üç nesneyle bile gerçekleşebileceğiydi. Doğruluk oranları (yüzde) ve cevap süreleri (milisaniye) sonuç değişkenler olarak karşılaştırıldı. Doğruluk oranları sonuçları contour ve crowding'in bir arada bulunamayacak iki kavram olduğunu göstermiştir. Ayrıca, doğruluk oranlarının analizi, üç nesnenin basit doğrusal şekiller oluşturmak için yeterli olduğunu ancak dairesel şekiller oluşturmadığını gösterdi.

Anahtar Kelimeler: contour etkisi, görsel crowding etkisi, konumsal konfigürasyon, görsel gruplama

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1. INTRODUCTION

Vision is the most dominant human sense (Krishna, 2006; Miller, 1972; Rock & Victor, 1964; Robinson, 1975). Therefore, other senses and even most of our cognitive abilities interact with it. It is also one of our most complex abilities (Hutmacher, 2019), and it has many sub-disciplines that are studied to understand the mind. Seeing is a vital mental process that is in a back and forward interaction with higher-order mental functions such as recognition, attention, and discrimination (Strasburger et al., 2011; van der Heijden, 2003; Campbell et al., 1970; Legge & Kersten, 1987). These functions enable humans to achieve daily activities by playing a game, playing an instrument, using a fork and a spoon, and driving a car. Like many cognitive functions, vision also has a limited capacity (Miller, 1956; Trick & Pylyshyn, 1994; Skehan, 2015). As one of the most widely accepted authorities on this topic, Miller explains how memory is limited around the number 2±7. He explains there are strategies to deal with these limitations. These strategies are namely, chunking, clustering, and mnemonics. Vision also has limitations such as masking effect and crowding effect. Traditionally low-level bottom-up perception was studied with rather simpler tasks like Vernier. In this thesis, we will focus on low-level contour integration and the configurational aspects.

1.1. Visual Perception

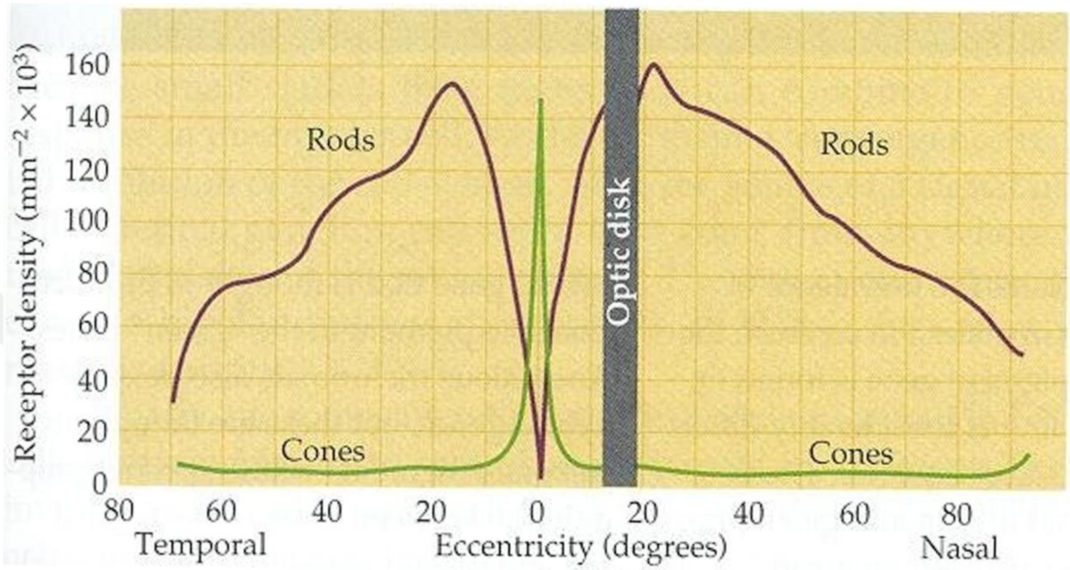
Visual reception is the most essential human ability for survival. It provides a high definition perception of the environment. The perceived images are processed in the brain and enable individuals to react. There are two distinct concepts at play. One is visual perception and the other one is visual processing (Lieberman, 1984). The former is the acquisition of information from the environment. However, these two concepts are equally significant for visual reception. In this thesis, the former one is subjected to investigation. Vision is in a strong relationship with many cognitive abilities (Cattaneo & Vecchi, 2011) and dominantly shapes how we measure and understand the world. One can only perceive depth, orientation, distance, size, and many other aspects with the help of visual perception. Problems in visual perception cause disorders in other functions such as sleep (Plomhause et al., 2014), eating (Engel & Keizer, 2017), mathematical calculation (Pieters et al., 2012), and auditory localization (Gori et al., 2014).

1.1.1. Anatomy of eyes

The development of the eye starts on the 22nd day of the fetus and continues to evolve until the 9th month (O'Rahilly, 1975). This proves that the eyes are one of the most sophisticated sensory organs that develop over a long period. The eyes are the tools of the brain to perceive the environment. It has been agreed upon that the brain only sees what eyes are signaling them. Meaning them this sight as many would describe is a phenomenon that occurs in the brain (Milner & Goodale, 2008; Tavassoli & Ringach, 2010). Light passes through the cornea into the retina. The light is then transformed into electrochemical signals via photoreceptors called rods and cones (Kaplan, 2007). These signals are received and processed in primarily occipital but different areas of the brain to create sight. The density of receptors changes on the retina. While cones' density is high in the foveal visual area, rods' density is higher in the peripheral vision area (Figure 1). Foveal vision is the central vision where highly accurate detail perception occurs. Peripheral and parafoveal visions on the other hand are low in precision.

Figure 1

Rods and cones density of the left eye



Note. From Cardullo et al. (2011). The Human Visual System and its Role in Motion Perception.

1.1.2. Visual attention

Like all memory-related cognitive abilities do (Cowan et al., 2004; Schacter, 1999), vision also has a limited capacity. One of these systems is selective attention which excludes unnecessary information from irrelevant stimuli from the environment (Ransley, 2018; Chun & Wolfe, 2001). Selective attention can happen before we directly look at the object with foveal vision (Ambler & Finklea, 1976). In their experiment Vater (2019), showed multiple moving targets with flanker items up to 25 degrees of eccentricity and detected active selective attention across the area. With the benefit of selective attention, peripheral vision perceives many different stimuli from the visual field and enables the brain to process them before saccading through.

1.1.3. Visual discrimination

Visual discrimination is a visual-cognitive ability that allows us to differentiate between two different items (Malik & Perona, 1990; To et al., 2011; Wright & Pitt, 1934; Watson & Robson, 1981). Discrimination tasks exceed the capacity of working memory and need long-term memory to recall the physical aspects of the item being compared (Kim et al., 2011; Maniscalco & Lau, 2015). For example, by recalling the shape of an object one can decide whether a certain fruit is an apple or a pear. To achieve the comparison of the two, also object recognition of the visual perception is necessary. In absence of a proper visual perception, this mechanism would not work.

1.1.4. Object recognition

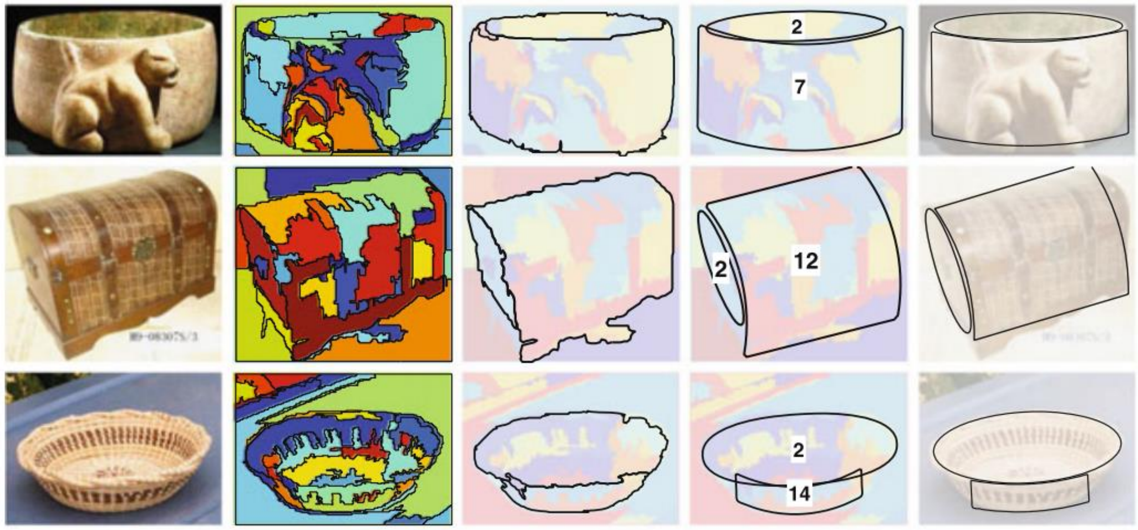
Being one of the most discussed topics of vision, object recognition is a multilayered process involving higher and lower order processing. The process includes the perception of color, size, shape, configuration, orientation, and making sense of these aspects with the help of cognitive abilities. The task of visual recognition can start from a lower order processing and move towards a higher-order (Spirkovska & Reid, 1992; Bar, 2003). The process is described as a cascade of reflexive feedforward (mostly) computations, resulting in a neural representation in the inferior temporal cortex (IT) which is highly related to face and number recognition (DiCarlo et al., 2012). In the case of face recognition, the process starts from simpler aspects like edges and corners (V), then moves onto shape perception(V2) followed by an object recognition (V4) that would eventually end up the phenomenon called face recognition(IT) (Biederman, 1987; Farah et al., 1998; Manassi et al., 2013). Object recognition plays a crucial role in survival in nature. We use this system from very primitive danger detection to the most sophisticated activities like enjoying a piece of artwork. Without object recognition, most of the daily activities would not be possible to perform (Engel & Keizer, 2017; Paulesu et al., 2014). As a result of being in constant use, it has a layered maximization system at work to lessen the workload while increasing its effectiveness (Gobet et al., 2001).

1.1.5. Shape perception

One of the lower-level forms of object recognition is shape perception. Shape perception oftentimes starts in the peripheral visual area and is a composition of sub-components such as edge, color, size, and movement perception (Figure 2) (Biederman, 1987; Marr & Nishihara, 1978). It helps to group, clutter, or discriminate the shapes around the attention area at a basic level. Although this selection is necessary for many tasks like discrimination of danger in the environment, sometimes it results in altered or incorrect perception. Let's say a snake is coming toward a person in the grass, the peripheral vision groups the color of the snake and grass into different groups and directs the attention to the snake even if it is partially visible in the grass. But the results would not be the same if the snake was crawling amongst many ropes on the ground or had green scales. While many predators in the natural use visual discrimination, many preys developed different skills to blend in with the environment. At the neurological level outer lines like corners, edges, and lines (to say created by the grouping effect) are one of the first to stimulate the visual cortex. Studying shape perception in simple forms to see the grouping and visual crowding effect has helped the cognitive science community in many ways throughout the years.

Figure 2

Visual Description of Color, Edges, and Shape Perception



Note. Dickinson & Pizlo (2013). Shape perception in human and computer vision. Springer.

Object recognition requires visual constancy, closure, and figure-ground discrimination to establish recognition. Constancy refers to the consistent recognition of objects with different aspects such as size, orientation, and color (Harris & Dux, 2005). Closure refers to filling the gap in the visual information to establish recognition (Foley et al., 1997). For example, skip lines on the road are recognized as one big line that divides the road into halves. Figure-ground discrimination refers to the differentiation of an object from the background even with distracting aspects. Most famous examples are background-foreground illusions.

1.1.6. Visual Crowding effect

Visual crowding is a vital phenomenon in visual perception because in natural scenes objects are most of the time crowded and they rarely come isolated to sight. (Figure 3a) For example, a stone is always surrounded by other stones. Crowding objects in natural scenes resulted in accordingly evolved visual systems. In natural scenes, visual crowding is the interruption of the perception of an object by the surrounding similar objects (Chakravarthi & Pelli 2011). Most commonly articulated as the perception of a target being deteriorated by the flanking elements. (Manassi et al., 2013) Coates et al. describe it as the adverse effect of nearby flankers on the identification of the target (Coates et al., 2018). Also, Levi describes it as a deleterious influence of nearby contours on visual discrimination (Levi, 2008). It is natural to conclude that visual crowding is an inhibitory effect on the perception of certain targets in the vision area. (Figure 3b)

Figure 3

(a) Crowding Example From an ambiguous Daily Scene. When looking directly at the fixation point in the middle, due to the surrounding objects and the colors it is difficult to detect the running boy on the left side, while the other boy on the right side is visible. (b) While looking at the fixation crosses it is difficult to identify the middle shape, letter, and line due to the surrounding similar objects

Note. Whitney, D., & Levi, D. M. (2011). Visual crowding: A fundamental limit on conscious perception and object recognition. Trends in cognitive sciences.

Visual crowding can occur all across the visual field, however, it is difficult to create a crowding effect in foveal vision as it is highly definite. Bouma (1970), discovered a critical spacing system of crowding. Critical spacing calculates the distance between the items according to their eccentricity. Other studies also found that the crowding amount is not related to the size of the items and is related to the eccentricity and the area in which the items are located (Levi et al., 2002; Livne & Sagi, 2007). These areas are relatively larger in peripheral vision as they get further away from the fovea

(Toet & Levi, 1992). In this thesis, the critical area is applied and the distance between the target and flankers is calculated according to the eccentricity.

Changing the number of flankers is a common practice in crowding experiments. Poder (2012), used 2,4 and 6 visual objects around the target and found that in “2 flankers” conditions the crowding did not happen. As the number of crowding objects increased the effect got stronger. We expect that due to the low eccentricity (4 degrees) the items appear close to the foveal vision and crowding did not happen with small numbers of elements.

In Livne & Sagi's (2007), experiment, they used 6 to 8 flankers around the target and created contour perceptions. They found that when the flankers grouped by creating a contour, the target is perceived better. The crowding effect vanished as the target popped out. In our design, the target is also a part of the contour elements.

Understanding the visual crowding might elucidate object recognition. It happens in peripheral vision and it is an intrinsic limit to early object recognition. It represents the bottleneck that interferes with object recognition. Visual crowding does not usually affect the detection but the discrimination and recognition. It reduces or alters the information gained from the target. Pooling and substation are two models that explain the effect. Both models agree with the feedforward and hierarchical process of object recognition.

1.1.6.1. pooling model

Pooling is, as the name suggests, the gathering of the information from the target and the flanking elements rather than losing the information. The information could be positons, orientations, sizes, colors, distances, etc. Parkes et al. (2001), suggested that even though participants were not able to tell the individual orientation of the target, they were successful in estimating the average orientation of the target and flanker. To give a simple example, if X number of targets are oriented with the amount of A and other elements of the population P-X is not oriented, the average orientations would be calculated with the proportion of X (Balas et al., 2009; Rosenholtz et al., 2012). This indicates that crowded orientations are pooled in the primary visual cortex before they are brought to a conscious investigation. Although it sounds like a loss, it is necessary to be able to obtain information from the big picture. For example let us imagine a person that had looked at a garden, and tried to remember the flowers from the memory. It would not be practical to remember all the individual differences of all the flowers. If there were different tones of red flowers, finding an average tone and applying it to the image when recalling is what pooling represents.

1.1.6.2. Substitution model

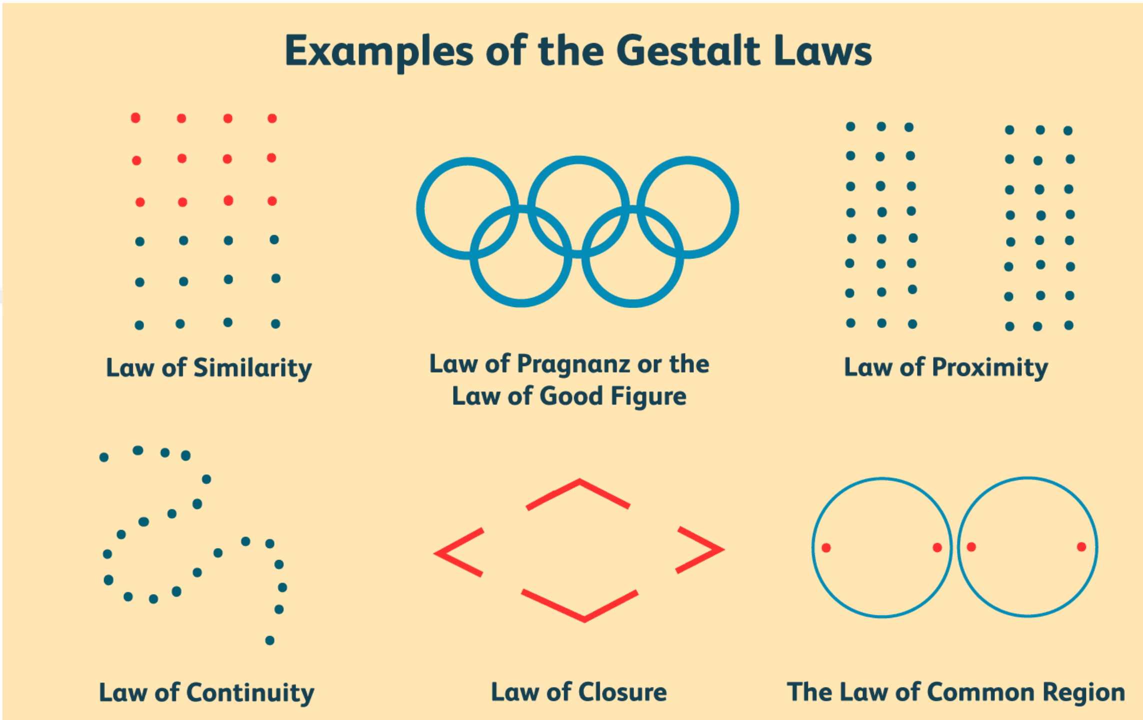
Substitution models explain the effect as the result of mislocalization (Huckauf & Heller, 2002) or attentional limitation (He et al., 1996). In substitutional crowding, participants respond with the false information obtained from the flanking element (Poder & Wagemans, 2007; Huckauf & Heller, 2002; Strasburger, 2005). Substitution might be the result of locational ambiguity or lack of attentional selection. Including substitution models, any kind of visual crowding that is not pooling is considered a non-pooling model (Freeman et al., 2012). In this thesis, substitution is not expected to occur as the positions of the target and flankers are constant and clear to the participants.

1.1.7. Visual grouping

Another commonly discussed phenomenon is the grouping effect or association field. Some studies suggest that crowding connate happens without grouping (Manassi et al., 2013). The grouping effect is the perceptual illusion that occurs when the visual systems intake certain characteristics of items and group them. These characteristics play a crucial role in the creation of visual crowding (Sayim & Cavanagh, 2013; Chung et al., 2001). In Gestalt Theory, these characteristics are described under certain laws as follows, similarity, proximity, continuity, closure, common region, the law of good figure, and connectedness (Spillmann, 1997). (See Figure 4 for the depictions of the laws.) In the law of continuity, people perceive aligned objects as belonging to a group rather than individual items (Loffler, 2008: Smits et al., 1985). The Law of common region supports that we perceive items together when they are in the same closed area. In the law of closure, the human brain is tended to perceive complete shapes to reduce the workload and generalize. As a result of this tendency, the gaps between items are filled in and it is called closure. The common region is oftentimes used to make texts easier to read by putting them on the same background (text boxes). In proximity, items close together are grouped.

Figure 4.

Examples of Gestalt's Laws



Note. Cherry, K. (2021, April 25), "Gestalt Laws of Perceptual Organization"

The grouping is assumed to happen at a very early stage in visual processing (Polat, 1999; Tannazzo, 2014). The effect takes place mostly in peripheral vision first. Then with the help of attention, the viewer starts to saccade and take the items under the foveal inspection if needed. In other words, the grouping effect is an inattentive peripheral vision and under normal circumstances (in daily life) works in the absence of attention (Julesz, 1980). To explain it in a broader concept, it can be referred to as an exhibitory effect of nearby objects on the perception of another in the peripheral vision area. Assuming that grouping happens after a certain threshold of orientation, closure, and placement congruency, there must be a minimum amount of these requirements to meet.

The crowding and grouping effects are frequently observed and studied together. They use common mechanics (May & Hess, 2007). Alignment and closure increase both the visual crowding and grouping.

It has been observed in earlier studies that different parameters can help to create visual grouping (Greenwood et al., 2012). In Figure 5 we can see an example of grouping created only with orientation adjustment. When we look at the scene we can see that gabor patches are creating different patterns. In Figure 6 all the parameters are the same except for the distances between the flankers. There are not any actual corridors or blocks of flankers but still, the eyes perceive as if there were.

Figure 5

Grouping as a Result of Orientational Congruency

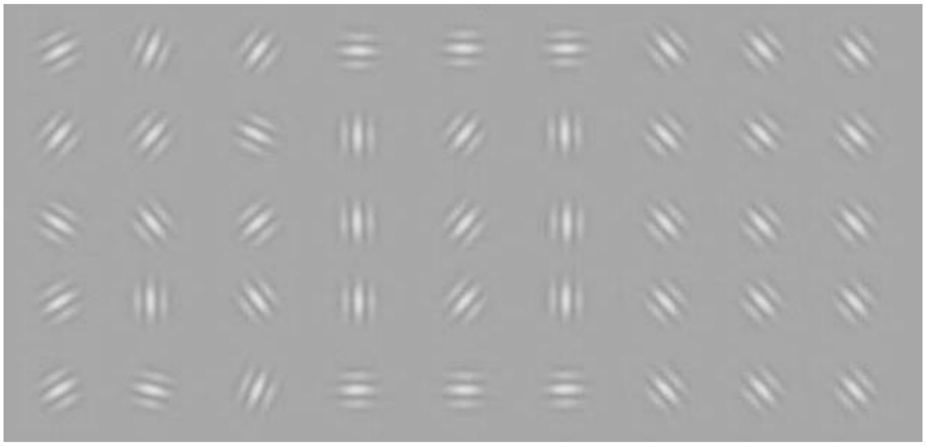


Figure 6

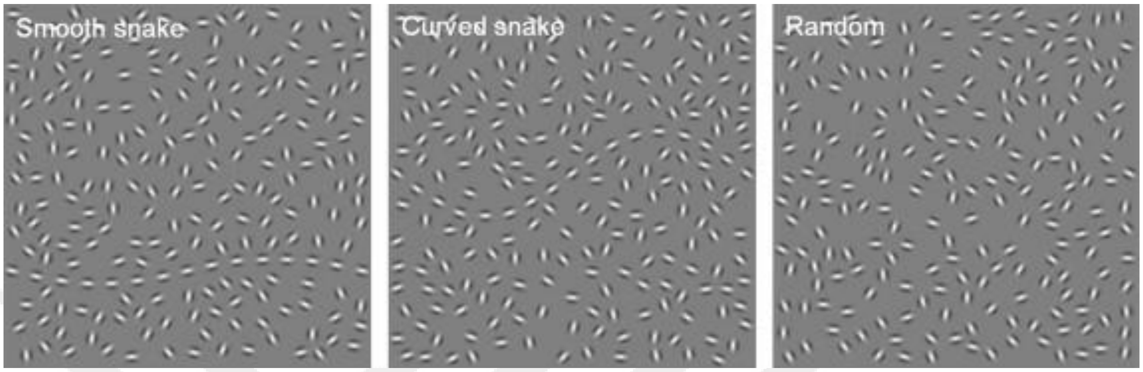
Grouping as a Result of Positional Congruency

1.1.8. Contour perception

Contour perception is the tendency to connect individual elements to form a global picture in Bouma’s grouping area with Gestalt’s laws (Fieldz et al., 1993; Bonneh & Sagi, 1998). Primary Gestalt laws that play a role in contour perception are continuation and closure (Livne & Sagi, 2007). The perception differs from the crowding effect in the systematic alteration of the target's perception closer to the global picture. This perception type creates low-level simple shapes that can eventually alter the attention of perception (Duncan, 1984). In (Figure 7*)* one of the most famous contour perceptions is shown. In the first two pictures of the figure, a snake-like shape stands out among many gabor patches thanks to the continuity and closure laws.

Figure 7

One of the Most Famous Contour Perception examples called Snake Contour



Note. Vancleef, K., & Wagemans, J. (2013). Component processes in contour integration: A direct comparison between snakes and ladders in a detection and a shape discrimination task.

1.2. The aim of this study

1.2.1. Crowding and grouping related aim

Many different aspects can be used to create groupings such as color, contrast, luminance, etc. (McIlhagga & Mullen, 1996) but in this thesis, for the sake of clearance, we only focus on orientation and location-related aspects such as positional configuration, eccentricity, orientation, and contour level. These elements are the independent variables (IV). Reaction time and orientational discrimination accuracy are dependent variables (DV). The target and flankers are organized in a way that they would always group. By changing the independent variables visual crowding and contour perception is achieved.

Using both the visual grouping effect and contour perception in the same task we aim to compare the effects of two phenomena on visual crowding. Most of the studies either investigated the phenomena in different tasks or the same task but with different elements (Livne & Sagi, 2007). In this thesis, the experiment design, visual grouping, visual crowding, and contour perception could happen at the same time. In other studies, visual grouping and crowding have been commonly observed together. However, the contour alignment in those designs was either inclusive to the targets or crowding elements. We hypothesize that there is a certain level of closure or continuity level, up to which grouping occurs without crowding. Which positional configuration and orientation fuse the crowding effect is still to be addressed. To reach a conclusion, the orientations of the objects are constantly changed, and accuracy is collected to check the crowding effect.

Choosing the right eccentricity would be critical in this experiment. The problem in Poder (2012), was when there were 2 crowding objects, the crowding effects did not occur because of the small eccentricity. To avoid this 8 and 10 degrees of eccentricity were used so that the target gets crowded with two flankers.

Three studies suggest that there is no crowding when the task is “detection” or “coarse discrimination” of rather simpler visual aspects (Pelli et al., 2004; Levi et al. 2002; Poder, 2008). In light of these findings, choosing a task with the right amount of difficulty was important. With simple tasks, the crowding effect might not occur. Hereby, the task was chosen to be orientation discrimination and the orientation differences between two objects were kept as small as possible.

1.2.2. Contour related aim

Continuation law acts as a chain, and breaking the pattern with several objects might result in the termination of the whole perception. However, the number of divergent elements needed is related to the number of items and the strength of the contour. We hypothesize that the contour perception of three objects can be broken with only one outlier. To hypothesize that, first we had to assume that contour perception could be created with as few as three objects. We create the objects in a way that they are always positionally congruent. What we refer to as congruency in this study is, however, the orientational congruency along with the positional one. According to the positional configuration, the expected orientation for each object is determined. The objects out of this orientation range are regarded as incongruent. In each trial, the number of congruent elements is recorded to detect the minimum number needed to both create and break the contour perception.

Choosing the minimum number of crowding objects as 2 (3 with the target) would be a critical decision. Most often increasing the number of objects increases the chance of observing an increased crowing effect (Poder, 2012). For the sake of crowding, a higher number of objects was preferable. But to create the contour perception with the smallest possible number of objects, it had to be only three. With two objects, although it was possible to create contour patterns, observing the effect of “breaking pattern with one” would not be possible because the creation of contour needs at least two congruent elements. With two orientationally incongruent objects, it would not be possible to decide which one breaks the pattern.

We investigated how orientation and positional configuration contribute to the process of shape perceptions. For this, we used orientations that provide continuity as well as distortion. To be accounted for shape/contour perception, several individual elements must show congruency in a way that the continuation of this aspect across the elements, creates a common perception. We expected both positional configuration and orientation would have a significant effect on the level of crowding. Since it is peripheral vision and the amount of information that we can obtain is limited, it would be natural to assume as a more apparent aspect, continuity/positional configuration would play a more significant role. In the experiment, 4 different positional configurations were used.

It is one of the main interests of this thesis whether the contour perception influences the perception of the orientation of the target such that the target object appears as a part of the expected contour form. By creating the perception of a shape with the flankers on each side, it can be observed whether the congruent stimuli are altering the perception of the target towards the perceived shape. If the shape was a diagonal straight line, the orientation of the line would be 45 degrees, then it must affect the perception in a way that the target would be seen at 45 degrees, or at least biased towards 45 degrees from its original orientation. The key relation between contour and crowding here is that in crowding the target orientation would be distorted while in contour it would be systematically perceived closer to the path of the shape. To understand the existence of contour perception, the direction of misperception was monitored.

1.2.3. Crowding and contour related aim

In the previous studies, flankers created contours with each other and the visual crowding on target was observed separately. As a result, it was found that, when flankers created a contour, the crowding effect disappeared. In those experiments, the target was not a part of the contour pattern and the pop-out effect was seen as the target got highly distinguished. In this experiment, the target was also a part of the contour shape and a reverse effect was expected because the continuity and closure laws required for contour integration also increase the grouping and crowding. Theoretically when congruency is increased crowding would increase as well.

2. MATERIALS AND METHODS

2.1. Participants

Twenty-nine participants with ages ranging from 18 to 32 participated in the experiment. All participants had normal or corrected-to-normal vision. This experiment was approved by Yeditepe University Ethical Committee for Social Sciences and was in compliance with the WMA Declaration of Helsinki.

2.2. Apparatus and Setup

In the experiment, the stimuli were presented on a Samsung SyncMaster 997 MB CRT screen. The screen resolution was 1024-768 pixels with a 75 Hz refresh rate. The experiment is conducted on a computer running Windows 10. MatLab and PsychToolBox Extension were used to code the interface. Heavy-Duty chin rest 705011 was placed before the screen at a distance of 60 cm. The targets and flankers were presented on a light grey background with RGB values of (168,168,168). The room was dark to reduce the visual distractions. A standard QWERTY layout keyboard was used to collect responses. The experiment was conducted in Computational Neuroscience and Visual Perception (CNVP) Laboratory at Yeditepe University.

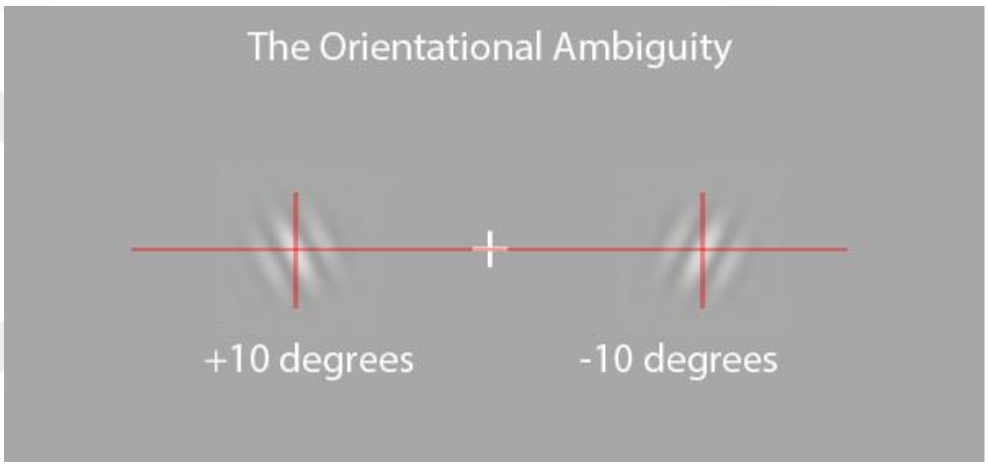
2.3. Stimuli and task

There were two flankers, one target on one side and another isolated target on the other side. A fixation cross was placed in the middle of the targets. Flanker and target images were gabor patches that had a spatial frequency of 3.5 cycles per degree (cpd) and a phase that placed a peak in contrast at the center of the patch. The Gaussian window had a standard deviation of 1.042 °. A base white (RGB: 255,255,255) cross fixation with a 3 mm length to each side was used. According to the participant's response, the fixation cross changes color to green (RGB: 0, 128, 0) for correct and to red (RGB: 255, 0, 0) for wrong. Each trial consisted of a 1000 ms stimulus and a 1000 ms response gap with a total of 2000 ms.

The targets (T1 and T2) appeared with an eccentricity of 8 or 10 degrees from the fixation point and the selection was random (Figure 12C). T1 and T2 switched sides randomly and first the orientation of T1 was decided between -90 and +90. Then the orientation of T2 was set to be different from T1. There was a fifty-fifty chance of the second target getting either a positive or a negative orientation difference. However, when the target's orientation is closer to 0, +90, or -90 there occurs an increased ambiguity while judging the closedness to the horizontal axis (Figure 8). To prevent this from happening a control mechanism was added to the code that checks for the condition and decides the second target's orientation without creating ambiguity.

Figure 8

Representation of Orientational Ambiguity. Red lines represent the horizontal and vertical axis. The orientation difference is 20 degrees and the first target on the left side is +10 degrees. The second target's orientation is created with a -20 degrees difference and has -10 degrees as a result. Orientation-wise, both targets are equally close to the horizontal axis.



One of the flankers was set to always appear on the upper and the other one on the lower side of the target. The upper and lower sides were split into left and right making two positions available for each target (Figure 12B). In the isolated cases, no flankers appeared.

2.4. Procedure

Participants were tested one by one. They were informed with an informative video. The video included examples of questions for warm-up purposes. Participants were asked to place their chins on the chin rest and place their fingers on the keyboard corresponding to the "left" and "right" arrows. After physical preparations, the screen instructed them to press the “space” button to start the experiment. Participants' performance was assessed with orientation discrimination accuracy. They were asked to select the target that is orientation-wise closer to the horizontal axis. (See Figure 9 for the samples.) Following the disappearance of the stimuli, participants had 1 second to respond. This makes the total duration of a trial 2 seconds. However, participants were free to respond while the stimuli were in sight, and 0.5 seconds after the participants' key press the next trial began. (Figure 10)

Figure 9

Depiction of the Orientation Discrimination Task

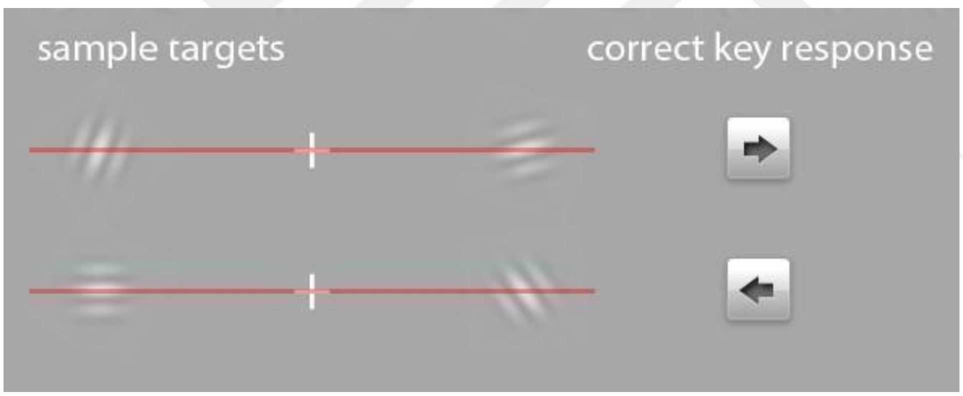
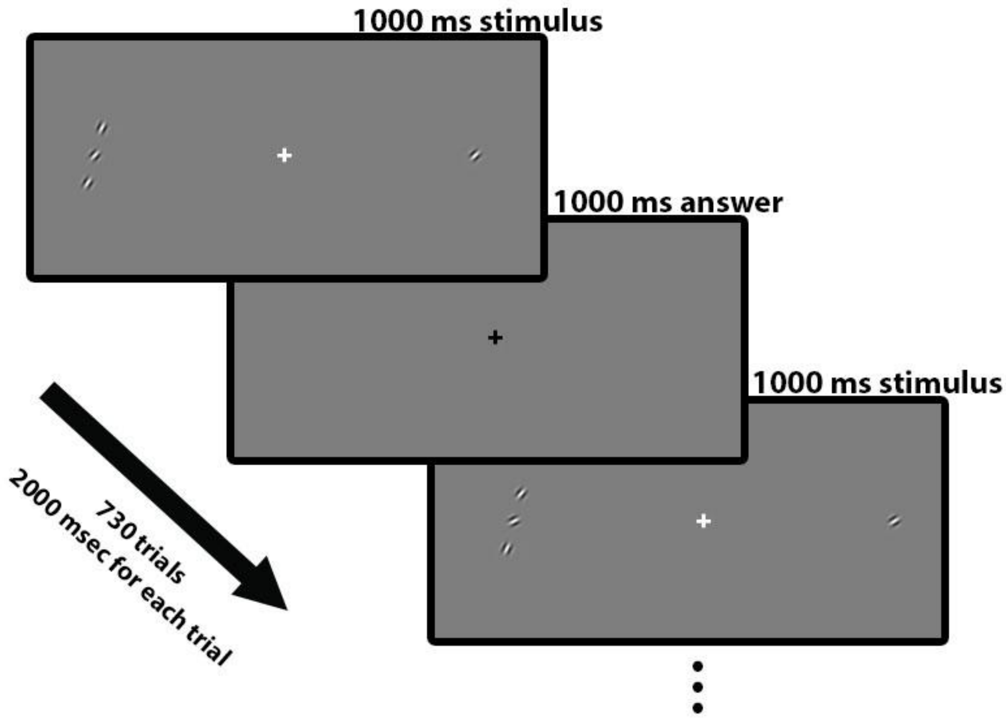


Figure 10

The Depiction of the Trial Mechanics



2.5. Pilot data

Inıtıally a pilot experiment was conducted and data was collected from 11 participants and 8030 trials. In the pilot experiment, the target to target orientation difference was set to 8 degrees. The overall success rate was at a chance level (mean = 0.59, SD = 0.49). The results indicated that the 8-degree difference was not enough to say that the orientational difference was perceived by the participants since the results were randomized and the chance to guess the correct answer was near %50 percent with two answers (left-right).

2.6. Pretest

To keep the accuracy rates in a standard interval, each participant went through a performance detection block before the main experiment. First, the fixation point appeared in the middle of the screen. Then two targets (T1, T2) simultaneously appeared on both sides of the screen. The stimuli were presented for one second and disappeared, only leaving the fixation cross on the screen.

The range of the orientation difference was kept between 5 to 21 degrees. Demo results showed us that most participants reach a sensible accuracy between 15 to 21 degrees (*Table 1*). Different sets of performance detection codes were prepared for all the orientation differences, however, all participants went through the 15 to 21-degree difference detection first. There were 25 instances of each orientation difference from 15 to 21) making up to 150 trials in randomized order. The results were fed into a psychometric function and the corresponding orientation difference of %80 accuracies is used to initialize the main experiment. The unsuccessful participants (in all orientation differences below %80 accuracies) did not participate in the main experiment. The overly-successful participants (almost in all orientation differences above %80 accuracy) participated in the 5 to 15 orientation difference performance detection block consisting of 250 trials.

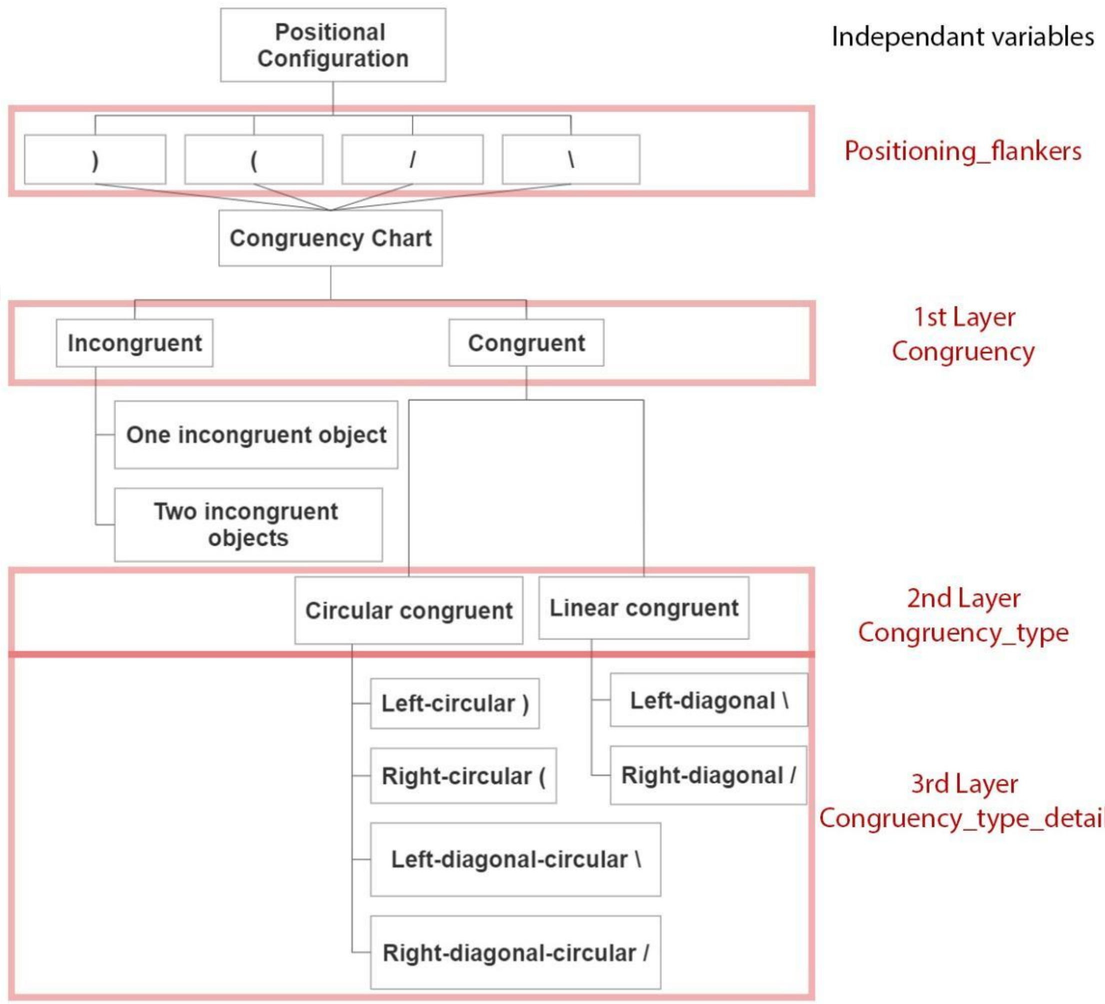
2.7. Main Experiment

The experiment consists of three blocks with 730 trials. The procedure is the same as the pretest in terms of the task. There were two differences. First, 720 of the trials consisted of an isolated target on one hemifield and a crowded target on the other hemifield, whereas 10 trials consisted of two isolated targets (as in the pretest) presented on both sides of the fixation. The 10 isolated trials were randomly scattered across the main experiment and used to test the null hypothesis. Second, the orientation difference of the two targets (T1 and T2) was fixed to the number decided in the pretest result.

In the main experiment, there were four positional configuration patterns either creating a diagonal line or a part of a circle shape and for each type to directions of left and right. All trials were treated as positionally congruent however what is being referred to as congruent in this paper is the orientational and positional congruency together. %18 of the trials were congruent. There is a three-layered (nested) system to assess the congruency in three different depths. In the first layer, the target-flanker configuration went under a binary classification where 1 represents congruent and 0 represents incongruent. In the second layer, the congruent group branched out in detail in terms of congruency type left-circle ")" where the target and flankers were grouped in a way that they look like they were the right part of a big circle. Right-circle "(" represents the opposite. Left-diagonal "\" and right-diagonal "/" were grouped to make straight diagonal lines to the related directions. In the third layer, the diagonal congruent conditions were branched out as there were also cases where diagonal positioning can create circle grouping with certain orientations. (See Figure 11 for the depiction of the layer system.)

Figure 11

Positional Configuration of Flankers and Depiction of Layered Congruency System



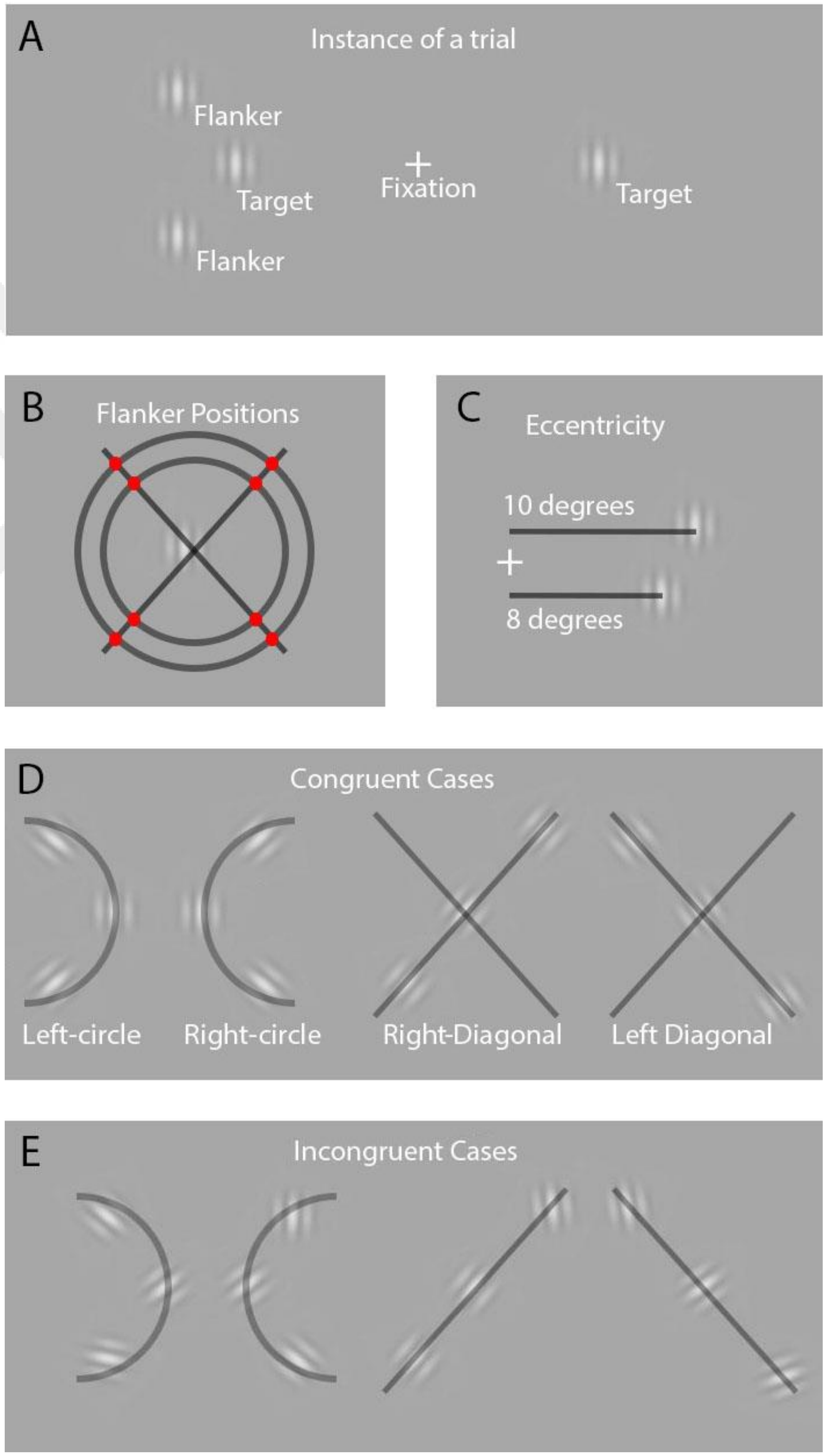
Positioning_flankers represents the positional configuration of the target and flankers. It is in a way the broader version of the Congruency_type. The main difference is, in Congruency_type, we only look at the positional configuration of congruent trials, whereas in the latter one all positional configurations were assessed regardless of congruency.

All the flankers and targets had either -90 or 90 degrees of orientation. Negative orientations rotated the items clockwise while positive orientations did vice versa. In case of a left-circle congruency, the upper flanker must be oriented between 30 and 60 degrees and the lower flanker must be oriented between -30 and -60 degrees. The target must be oriented between -30 and +30 degrees. The opposite of these conditions describes the right-circle congruency. In diagonal congruency, the conditions were a bit more delicate as there were two types of congruencies. First, the diagonal linear congruency was matched when the target and the flankers were all in between +22.5 and +67.5 or -22.5 and -67.5 degrees. In case these conditions were not matched, if the target was between +22.5 and +67.5 while the upper flanker was between +67.5 and +90 and the lower flanker was between -22.5 and 0 degrees it was matched with left-circle-tilted and the vice versa was matched with right-circle-tilted. (Figure 12D*)*

In (Figure 12) there were five sections to describe the visuals in the experiment. In 12A an illustration of a crowded trial is shown. There is a fixation cross in the middle of the screen and two targets on each side of the visual hemifield. One of the targets is crowded with flankers. The illustration in 12B shows us the possible locations where flankers can appear around the target. There were two circles. The inner circle is chosen when the Eccentricity is 8 degrees and the outer circle is chosen when the Eccentricity is 10 degrees. The eccentricity is illustrated in 12C. Two possible distances of a target from the fixation cross are shown. The shorter distance corresponds to 8 degrees and the longer distance corresponds to 10 degrees eccentricity. In 12D four possible congruent cases are illustrated with an imaginary line to indicate the expected contour pattern. In 12E there are a few cases of configurations where we can see orientational incongruencies.

Figure 12

Target, Flakers, and Congruency Configurations



The total length of the experiment was 24 minutes and 03 seconds however, participants could rest as much as they desired between the blocks. Once they responded, the next trial started in 500 ms. Each block lasted 8 minutes and 01 seconds and the first one was with extra 2 seconds because of the extra one trial ((730 trials -1 trial)/3 blocks). (Figure 10)The fixation point toggled between black and white to create a phase shift for the stimulus and response phases of the trials.

2.8. Statistical Analysis

To decide on a statistically sufficient number of participants, power analysis for logistic regression was applied to the data collected from 19 participants. To reach 0.8 power, the total sample size was 26 with a critical z of 1.64.

The collected data were analyzed using the One-way ANOVA. Dependent variables were namely, accuracy and reaction_time (seconds). Independent factors were Hemisphere (2 conditions: left and right), Eccentricity (2 conditions: 8 degrees and 10 degrees), Target_orientaiton_group (3 conditions: vertical, diagonal, and horizontal), first layer-Congruency (2 conditions: congruent and incongruent), second layer-Congruency_type (2 conditions: circle and diagonal), third layer-Congruency_type_detail (5 conditions: left-circle, right-circle, circle-tilted, left-diagonal and right diagonal), Congruency_Flankers(3 conditions: Incongruent, Congruent Flankers and All Congruent), Positioning_Flankers (4 conditions: “)” , “(“ , “\” and “/”) and Relative_Positioning(3 conditions: left-side, both-sides and right-side). The T-test was used for pairwise comparisons for significant conditions from ANOVA.

As the data was binary in accuracy results, logistic regression model was also used for analysis. Within-subject factors were hemisphere (2 conditions: left and right), eccentricity (2 conditions: 8 degrees and 10 degrees), Target_orientaiton_group (3 conditions: vertical, diagonal, and horizontal), first layer Congruency (2 conditions: congruent and incongruent), second layer Congruency_type (2 conditions: circle and diagonal), third layer Congruency_type_detail (5 conditions: left-circle, right-circle, circle-tilted left-diagonal and right diagonal), Positioning_Flankers (4 conditions: “)” , “(“ , “\” and “/”) and Variance (Scalar variance from 0 to 4400).

3. RESULTS

Overall performance was near just noticeable difference (JND) (mean = 0.77, SD = 0.419) in the performance detection task. There were 260 isolated trials (mean = 0.85, SD = 0.35) that had higher accuracy than 18720 crowded trials (mean = 0.77, SD = 0.42). Isolated trials (mean = 0.88, SD = 0.33) had slightly faster mean response time than crowded trials (mean = 0.87, SD = 0.33). In the pretest %85 of the participants took the test between 15 and 21 degrees target-to-target orientation difference (Table 1).

Table 1

Numbers of Orientation Differences used in the Main Experiment

Orientation Difference	**5**	**10**	**11**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of participants	1	1	1	1	4	1	4	4	5	5

3.1. Accuracy Analysis

3.1.1. The effect of congruency

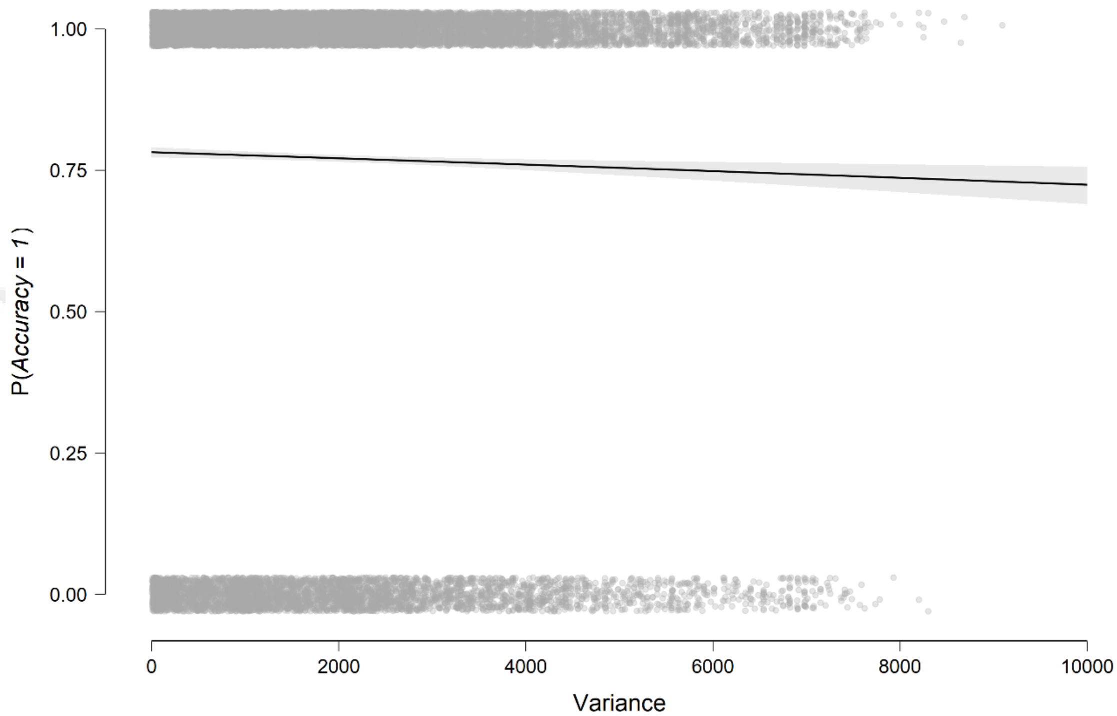
One-way repeated-measures analysis of variance (ANOVA) was conducted to determine whether there was a significant difference in accuracy. In the first layer analysis, the results indicated that Congruency $F(1,24) = 4.660$, $p = 0.031$, partial $\eta 2 = 2.486e-4$ and Target_orientation_group $F(2,23) = 3.105$, $p = 0.045$, partial $\eta 2 = 3.313e-4$ (Figure 14) had significant main effects on accuracy. The congruent trials (mean = 0.79, SD = 0.4) had a higher accuracy than incongruent trials (mean = 0.76, SD = 0.42).

3.1.2. Orientation difference level

The variance was calculated with the orientations of two flankers and one crowded target. Logistic regression model indicated a significance of variance on accuracy (P = 0.003, z = -2,987, Standard Error = 0.000). The distribution plot can be seen in Figure 13. The continuous line represents the trend and the gray area around it represents standard error while gray circles (small) on the upper and lower parts represent the number of correct and wrong answers.

Figure 13

The effect of Variance of target and Flankers on Accuracy



3.1.3. The role of contours

In the second layer, instead of Congruency, Congruency_type F(1,24) =1.313e -4, p = 0.991, partial η2 = 3.863e -8 did not show any significance.

In the third layer, Congruency_type_detail F(4,21) =1.384, p = 0.237, partial η2 = 0.002 did not show any significance. (Figure 16)

An additional analysis with Positioning_flankers was conducted to see the effect on accruacy. Positioning_flankers F(3,22) =3.442, p = 0.016, partial η2 = 5.514e -4 and Target_orientation_group F(2,23) =4.616, p = 0.010, partial η2 = 4.929e -4 showed consistent significance. (Figure 17)

3.1.4. Congruency and positioning

To see the relationship between Positioning_flankers and Congruency's effect on accuracy, the two were analyzed and Congruency $F(1,24) = 5.717$, $p = 0.017$, partial $\eta2 = 3.054e-4$ showed significant main effect. Post Hoc comparison test indicated that only inter-types (circle to diagonal) comparisons had significance (Figure 18). A two tailed paired samples t-test was conducted to determine the effect of congruency and positioning of flankers. The results indicated significant differences in three comparisons. First significance was between congruent-diagonal (M=0.795; SD=0.404) and incongruenct-diagonal (M=0.755; SD=0.004) cases; [t(1969) = -.002, p = <.001]. The second significance was between congruent-diagonal (M=0.795; SD=0.404) and incongruenct-circle (M=0.79; SD=0.407) cases; [t(4842) = -.017, p = <.001]. The third significance was between incongruent-diagonal (M=0.755; SD=0.004) and congruenct-circle (M=0.79; SD=0.408) cases; [t(1450) = .024, p = <.001]. Congruency_Flankers $F(2,23) = 7.381$, $p = <.001$, partial $\eta2 = 7.881e-4$ (Figure 20) and Relative_Positioning $F(2,23) = 9.889$, $p = <.001$, partial $\eta2 = 0.001$ showed significance.

Figure 14

Mean Accuracy for Target Orientation Groups

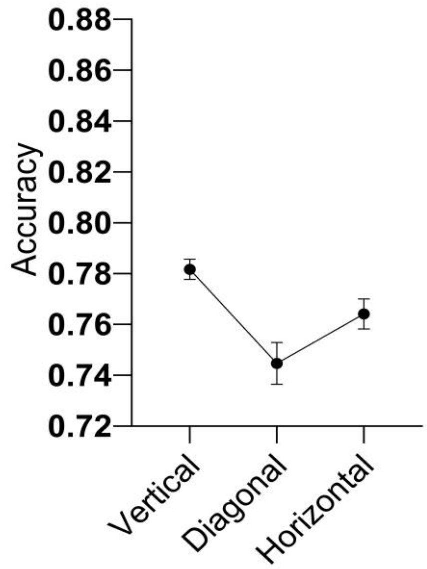


Figure 15

Target Orientation Group Accuracy on 2D Space. The lines around the area represent the orientation of the target

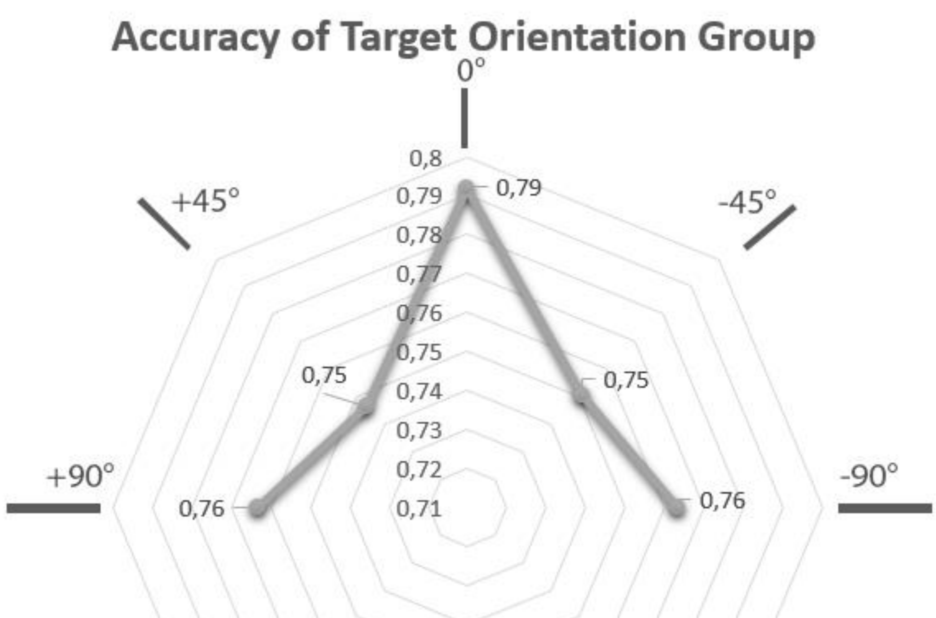


Figure 16

Mean Accuracy for Detailed Congruency Types

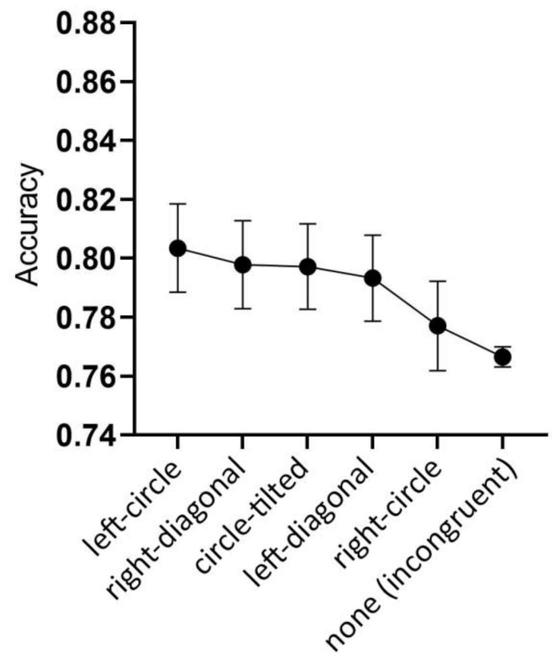


Figure 17

Mean Accuracy for Positioning of Flankers Around the Target

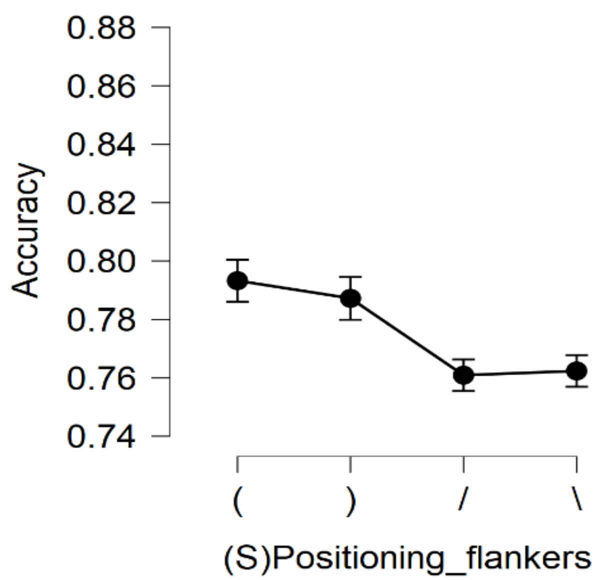


Figure 18

Mean Accuracy for Positioning of Flankers Around the Target Split by Congruency

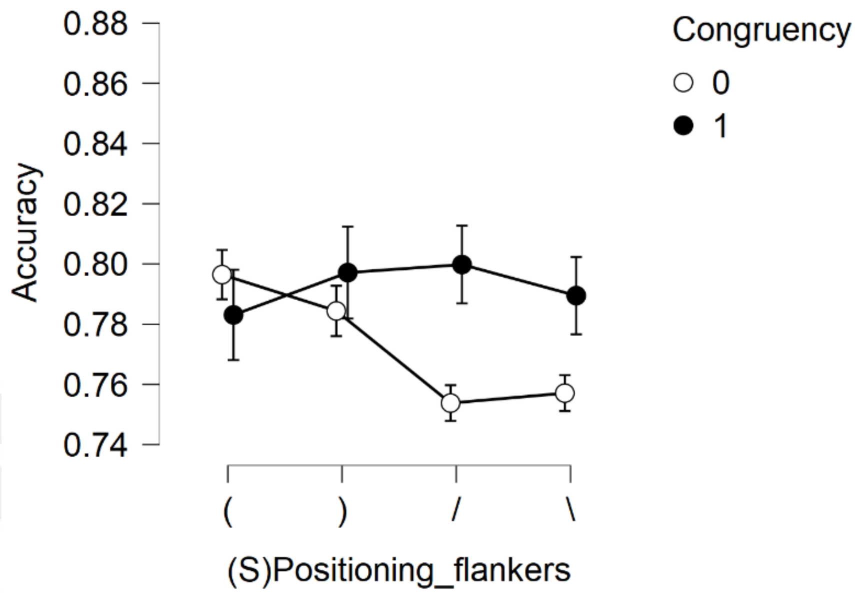


Figure 19

Mean Directional Bias of Diagonally Crowded Targets' Orientations

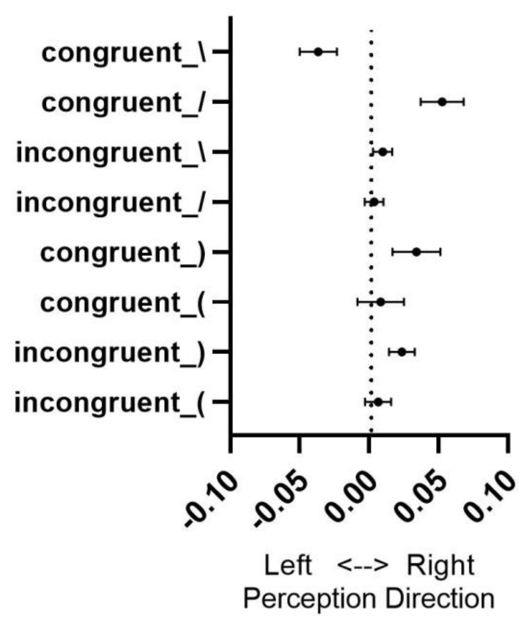


Figure 20

Incongruency, Flankers Only Congruency, and All Congruency Accuracy Results of Horizontal Positioning

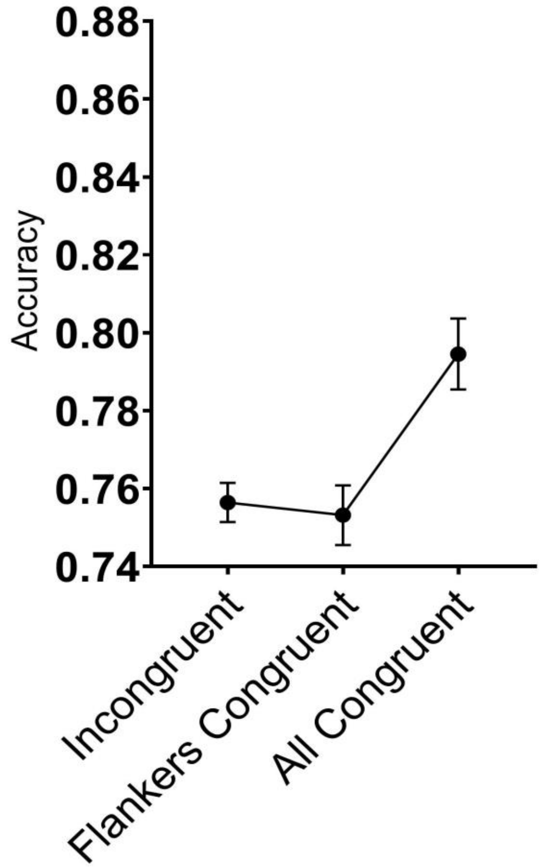
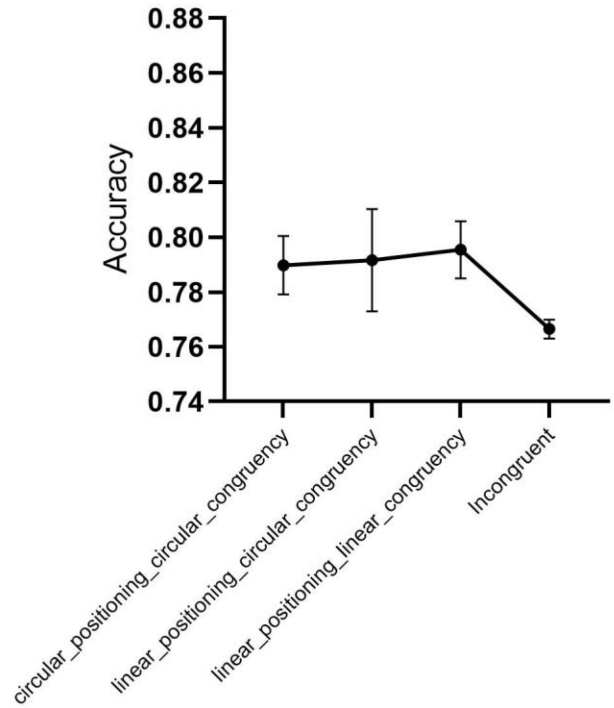


Figure 21

Mean Accuracy of circular, tilted circular and linear contour shape



3.2. Reaction Time Analysis

In terms of reaction time the data was normally distributed (mean = 0.87, SD = 0.33, Skewness = 0.92, Std. Skewness = 0.01, Kurtosis = 0.62, Std. Error = 0.03). One-way repeated-measures analysis of variance (ANOVA) was conducted to determine whether there was a significant difference of the following independent variables on reaction time. The results indicated that Eccentricity $F(1,24) = 18.758$, $p = < .001$, partial $\eta 2 = 0.001$ Congruency $F(1,24) = 16.666$, $p = < .001$, partial $\eta 2 = 8.876e\text{ -}4$ and Positioning_Flankers $F(3,22) = 2.868$, $p = 0.035$, partial $\eta 2 = 4.583e\text{ -}4$ had significant main effects on reaction time. Games-Howell Post Hoc comparison test indicated that 8 degrees eccentricity trials were responded significantly faster than 10 degrees (M = -0.021, SE = .005), incongruent trials were responded significantly faster than congruent trials (M = -0.029, SE = .007) and “(“ positioning were responded significantly faster than “/” (M = 0.023, SE = .007) and “\” (M = 0.024, SE = .006) (Figure 22). ANOVA results also indicated that interaction of Eccentricity and Positioning_Flankers $F(3,22) = 3.829$, $p = 0.009$, partial $\eta 2 = 6.118e-4$ also had significant effect on reaction time (Figure 23).

Figure 22

Mean Reaction Times for Eccentricity, Congruency, and Positioning_Flankers

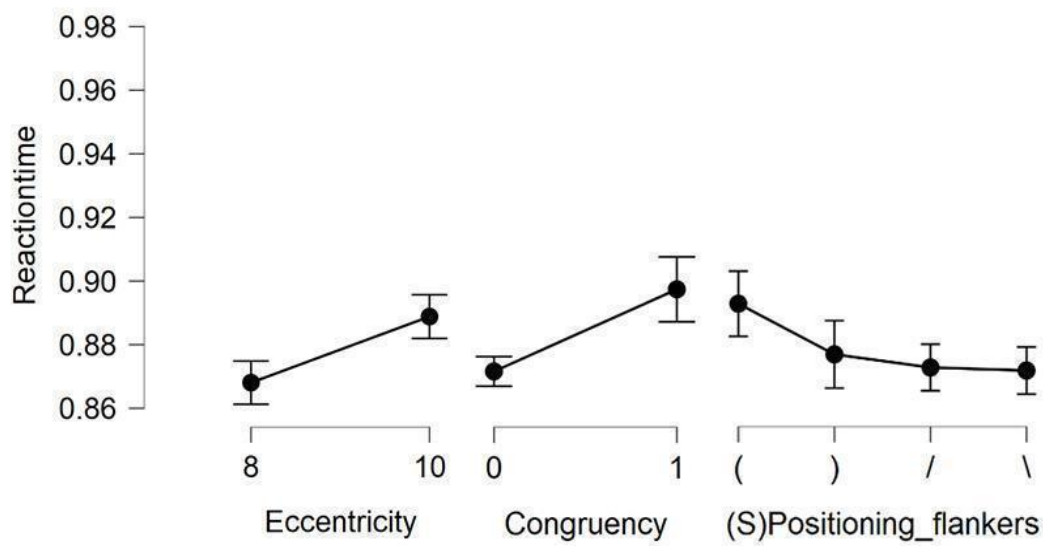
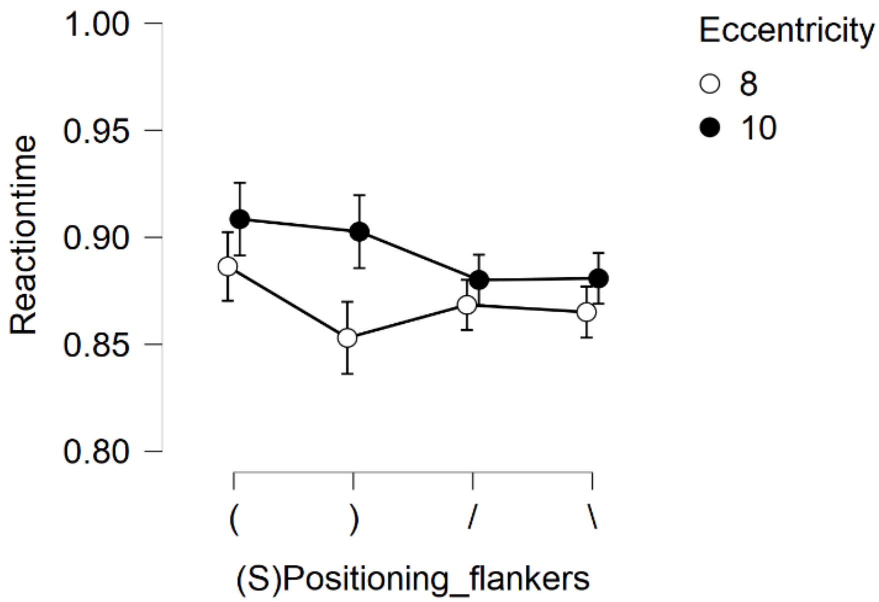


Figure 23

Mean Reaction Times for Interaction of Eccentricity Split by Positioning_Flankers



4. DISCUSSION

4.1. General discussion

We examined the effect of the orientation and the positional configuration of objects that are within crowding proximity, in an orientation discrimination task. Some of the configurations created a contour integration effect either creating diagonal/linear or circular patterns. The results are evaluated to understand the emergence of crowding and grouping and their relationship to contour integration.

Results indicate the occurrence of the crowding effect in all conditions as the accuracy rate of the isolated trials is significantly higher than others. A strong relationship between crowding and the relative positionings of the target and flankers was observed. In other words, how the flankers are positioned around the target is significant for target identification. In diagonal configurations and incongruent orientations, the crowding magnitude was the highest. When the orientation congruency increased, it reduced the crowding effect. This indicates that, as opposed to our hypothesis, contour perception does not increase the crowding effect. The variance of target and flanker orientations correlates with the crowding level (Figure 13). As the orientation difference between the visual objects increased, the crowding level also increased.

4.2. Target orientation effect

When we look at the main effects, congruency, and targets' orientation category (Figure 14) affected the results significantly in the first layer analysis of accuracy. The continuity and the proximity of visual objects sufficed to create a crowding effect. When the continuity and proximity were accompanied by closure the crowding effect did not occur as much. In post hoc tests there were significant differences between vertical (1) and diagonal (2) along with vertical (1) and horizontal (3) target orientations. In the case of vertical targets, the accuracy was highest followed by horizontal targets. The diagonal targets confuse the participants the most and result in a lower accuracy rate (Figure 14, 15). Figure 15 visualizes the accuracy for target orientation groups in a 2D space. An explanation for this might be that in all trials the location of flankers was positioned diagonally to the target. As a result, diagonally oriented targets were easier to group with the flankers.

4.3. Higher accuracy with contour integration

To see the effect of contour integration, congruent trials were examined in three layers. In the first layer analysis, congruency had the most significant effect on the rate of accuracy as expected. Although we expected a main effect of congruency, it is unexpected that the congruent trials have higher accuracy. There are two possible explanations for the higher accuracy of congruent trials in the literature.

The first explanation is the "pop-out effect". This effect takes place when the flankers of a visual object in a scene group with each other and decrease the crowding magnitude (Kooi et al., 1994; Poder, 2008; Felisberti et al., 2005; Manassi et al., 2013; Saarela et al., 2009). The grouping of flankers is supposedly making the difference between target and flankers more apparent. To test this hypothesis, incongruent trials are divided into two sections. In the first section, all the objects had incongruent orientations. The second section consisted of trials in which the flankers are congruent with each other but the target's orientation is incongruent. The results did not support the existence of the pop-out effect as the incongruency and only-flanker-congruency did not have any significant difference (Figure 20).

Second, some studies suggest that when the number of items in a crowded scene increases, up to a certain amount, crowding occurs but when this amount is exceeded, the crowding effect gradually decreases (Poder, 2006). It can be understood that excessive crowding magnitude may result in a pop-out effect. But in our experiment, the number of flankers was constant and minimal. This refutes the pop-out effect.

4.4. How contour types affect the accuracy

In the second layer of analysis, instead of Congruency, Congruency_type was examined. Congruency_type did not show any significance but in the first layer analysis, the Congruency significantly affected the result. To locate the source of significance, the interaction of independent variables of the first and second layers needed further investigation.

The interaction of the two layers was examined using Positioning_flankers and Congruency. Positioning_flankers is the broader version of Congruency_type because it also includes incongruent trials. It represents the positional configuration of all trials as ")", "(", "/" and "\". Congruency simply represents the orientational concordance of the visual objects. The positional configurations and their interaction with Congruency affected the results significantly. Post Hoc comparisons indicated that there were significant differences between all pair-wise comparisons of diagonal to circle positioning (Figure 17). When positional configurations were analyzed by splitting the data by congruency, two outcomes were observed. First, congruency did not affect circular configurations while diagonal-linear configurations did (Figure 18). In figure 18 it is clear that the accuracy rate of circular trials is close to each other while in linear trials there is a difference. Second, the accuracy was low in incongruent diagonal-linear configurations (M=0.755; SD=0.004). The source of the low accuracy rates in incongruent trials is the diagonal-linear configurations (Figure 18). In Figure 21 congruency types have similar accuracy rates even though the positional configurations are different. This means that without closure, continuity is not enough to create contour perceptions.

4.5. The effect of the flanker's position on the accuracy

When all the results above are considered, three observations can be made from the pairwise comparisons.

The first one is when the configuration of the items is diagonal/linear, they are vulnerable to crowding. The low accuracy rate in diagonal grouping indicates the existence of a high magnitude of crowding effect. In circular grouping, it indicates a lower magnitude of the crowding effect. Diagonal contour patterns were linear while circular patterns were curvy. Linear continuity creates a simpler shape than circular continuity. Simple straight shapes are less complex than circular shapes in terms of orientation. When creating a linear contour all three items must be in the range of 45°. While creating circular shapes this range expands to 135°. As a result, the pooling process is easier in straight contour shapes. Also, in hierarchical theory, sharp-edged shapes are processed earlier than soft edges ones (Memis & Yildirim, 2021). Sharper shapes naturally consist of straight outlines thus the diagonal contours in our experiment were easier to perceive. These might explain why we observed a higher magnitude of crowding in diagonal positional configurations. The findings of previous studies are coherent with this conclusion (Malania et al., 2020; Kewan-Khalayly et al., 2021, Preprint; Poder, 2008; Whitney & Levi, 2011). This supports the hypothesis that positional configuration is relatively more significant than orientation in creating the crowding effect.

The second observation is that when the contour integration is present crowding magnitude is reduced by %3. We already eliminated the possibility of a pop-out effect.

Figure 20 shows that even though the flankers are congruent with each other, the target breaks the contour pattern and items get as crowded as normal.

The third observation is that when the objects are congruent their orientations are naturally close to each other. The items in the range of 22.5 degrees of the contour shapes' axis are accounted as congruent. If the orientations are close to each other, even though the items are crowded, the altered perception would still be close to the actual orientation. In short, the difference between the average taken from the pooling effect and the real orientation is small. This would explain why the crowding effect magnitude is lessened as opposed to the results of previous experiments. When the target is one of the contour objects, contour perception acts as an inhibitor for crowding. The pooling effect is easier to take place when the items are similar to each other. In incongruent trials, there is too much information to process resulting in a higher magnitude of crowding.

These three assumptions point out that crowding and contour might differ mainly according to orientation congruency.

Objects forming simple patterns, like a line, are easier to crowded compared to complex ones. One could ask whether the contours were created or not. To answer that we ran an additional analysis on the target's perceived direction in inaccurate trials. The results showed significance in diagonal configuration between congruent and incongruent conditions (where we have also seen the high crowding effect). Figure 19 shows the mean directional bias of the target's orientation. The left side of the graph indicates a perceptional bias towards the left side and vice versa. "Left-diagonal" congruency created a bias to left and "Right-diagonal" created a bias towards the right side. This indicates that contours affect the perceived orientation expectedly. The findings support both of our hypotheses. Three items are enough to create a contour perception. When one of the items, in this case the target is incongruent, the contour perception disappears. This answers the question that whether one object can break the pattern or not.

The bias of the target in incongruent-diagonal trials supports the pooling models. When contour patterns are created with both positioning and orientation, the orientation of the target appears closer to the orientation of the overall shape. It is natural to assume that the objects in the crowding area are pooled and as a result, an average orientation is assigned to each item. We do not explain the results with the substitution models as the target's position was always clear to the participants and explained before the experiment. The assumption of participants not getting coherent information about the target is rejected as the bias of perceived direction assures that there is a systematic alteration rather than a random one.

4.6. Relative positions of flankers affect the results

The relative positioning of the flankers has more effect on the level of crowding than the eccentricity or proximity. When we examine Figure 16, it shows us Congruency_type_detail accuracy results. Keep in mind that all the results in the right hemisphere are symmetrically converted to the left side. There are three conditions in terms of positioning types:

1. In the “right circle” both flankers are on the inner/right side of the target.
2. In the “left circle” both flankers are on the outer/left side of the target.
3. In both left and right “diagonal positioning” one of the flankers is always on the right and the other one is always on the left side of the target.

It can be observed from this graph that the more the flankers are between the target and fixation, the higher the crowding magnitude is. In our results when two flankers are between the target and the fixation cross (right-circle) crowding is higher and when one (right-diagonal, left-diagonal, circle-tilted) or none (left-circle) of the flankers is between target and fixation the crowding is lower. In the previous studies, it has been found that in peripheral vision the crowding effect is higher when the two flankers align radially rather than tangentially (Kewan-Khalayly et al., 2021, Preprint; Poder, 2008; Whitney & Levi, 2011). This means that flankers crowd more when they were on the left and right side of the target rather than above and below. This is coherent with our findings.

Cavanagh (2004), suggests that crowding is strictly related to the size of the area and the number of information available within. When there are multiple flankers nearby the target the information we get from the target is limited. With multiple numbers of flankers (let us say 8) it is highly probable that complex information, in this case, orientation, gets crowded. With two flankers that we used, orientation was accessible. What interfered with the crowding was the positional configuration. However, with the current results, we do not exactly have the means and knowledge to elaborate on the effects of visual patterns (Positioning_flankers) and what kind of information they bring into the equation.

What we have investigated here is the initial step of object recognition. Object recognition starts with shape perception and shape perception is initiated with the detection of simpler aspects like edges, corners, size, etc. A shape can be perceived even by just looking at a part of the shape. By creating a contour perception of curvy and linear lines we tried to create parts of bigger shapes. It can be understood that in shape perception there is a priority on the perception of straight and edgy aspects. This might be the result of survival animal instincts. As an instinct, people react to edgy objects more intensely and faster (Larson et al., 2009; Bertamini et al., 2016). These kinds of stimuli trigger higher amygdala activation as they represent a threat while curvy aspects give a sense of safety. We can see the survival perceptual selection even in simple contour shapes.

4.7. Shape perception occurred in congruent trials

We found evidence of the occurrence of shape perception in congruent diagonal trials (Figure 19). When the target and flankers were in left diagonal configuration (e.g. "\") the participants perceived the target more oriented to the left than it was. The opposite perceptional tendency was observed in the right diagonal trials. Participants perceived the target's orientation as closer to the axis of the shape created with contour. The same tendency was not observed in incongruent trials or circular configurations. This indicated that both positional configuration and orientation congruency are determinative in shape perception. Proximity and continuity were necessary for shape perception but they were not enough without orientation congruency.

In circular contour shapes, we only created the perception of the portion of a circle. This portion was approximately around a quarter of the whole shape. The participants were expected to perceive a portion of a big circle. However, in linear contour shapes, it was simply a matter of the length of the shape and can not be regarded as a missing piece. It is possible that the contour was perceived as a short line rather than a part of a long line. This might have created an extra cognitive load on the circular contour shapes as there are more pieces to be filled in for. As a result, we have only observed contour perception in linear shapes.

4.8. Limitations

Since the stimuli were randomized, some specific conditions, like congruency types were small in number. It is simply a matter of how we define as congruency. There is not much in the literature to help with specific experiment designs like this one. The term "congruency" itself is too vague to describe and make assumptions.

One limitation of the setup was that the eye movements of the participants were not recorded and the possible miss trials were not removed whereas only the verbal confirmation was taken. Some participants reported in one or two trials they got distracted from the fixation point but the precise trial numbers could only be achieved by an eye-tracking device. Yet, the overall desired level accuracy of participants in the task indicates that the fixation task was carried out.

Another limitation of the setup was that when we divided results with congruency and positional configuration, the number of trials drops sarcastically. After the division, the number of trials in each group makes up %2.2 (Mean = 427.75, Standard deviation = 66.4) of all trials. The small number of trials for each chase might have resulted in an unstable accuracy rate.

4.9. Future studies

In the experiment, only the performance of the orientation discrimination is assessed. A replication of the experiment can be conducted with a task where participants respond indicating perceived position and orientation. Doing so might give a better understanding of the visual crowding and grouping's effect on spatial perception. Also, increasing the number of flanker points would ideally provide better insights into the relative positioning of flankers.

5. CONCLUSIONS

By implementing contour perception to a crowding task, we have observed the relationship between the two phenomena together. Current studies supported the idea that grouping and crowding co-exist. This is merely a result of crowding and grouping using the same mechanics (Ma & Hess, 2007). The positioning of flankers around the target was critical for crowding. Positioning was dominant over the orientation-related features. We have analyzed multiple levels of congruency. Being congruent or incongruent made a significant difference and congruency types (e.g. left circular, right circular, left diagonal, and right diagonal) did not affect the results. We observed that linear configurations increased crowding magnitude more compared to circular configurations. Contrary to the literature, our results indicated a high accuracy in congruent trials. The higher accuracy in incongruent compared to congruent trials was the result of the lower crowding magnitude in congruent trials (e.g. incongruent right diagonal, incongruent left diagonal).

In our experiment, we kept the continuity of the items in accordance with the proximity law and this resulted in a constant grouping. The grouping also created a crowding effect. Particularly, when linear continuity and closure were present, the crowding magnitude was the highest (Figure 21). This was in accordance with the pooling and hierarchical models. Initially, we started with grouped objects and as a result, these objects got crowded with different magnitudes. When these items created contour patterns, the crowding magnitude decreased considerably while the law of continuity and closure still existed. We have provided evidence that simple contour perceptions can be created even with as few objects as three and these perceptions can be terminated with one incongruous object.

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