THE EFFECT OF CONTOUR AND CONFIGURATION ON VISUAL CROWDING

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THE EFFECT OF CONTOUR AND CONFIGURATION ON VISUAL CROWDING

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PLAGIARISM

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Visual crowding refers to poor target identification performance due to the presence of flankers. Even though crowding studies mostly presented for low level stimulus settings, it is observed in high level settings as well such as faces and configuration. This study is aimed to investigate the effect of contour type (sharp-edged vs curve-edged) and configuration type (random vs smooth) with two experiments in crowded scenes. We hypothesized that the sharp-edged contours should be reacted faster for and more accurately compared to the curve-edged ones due to assumption of hierarchical and pooling models. According to both models, objects are recognized in a hierarchical way such that low-level and high-level features are orderly processed in the cortex. Sharp-edged contours might have an identification advantage due to comprising simple lines and intersections whereas circle does not have obvious components as the triangle has. We also expected that random configuration trials to have better outcome rates compared to regular and irregular ones because grouping can make detection of the target harder due to the similarity between target and flankers. We performed two experiments where we controlled configuration and contour respectively. We compared reaction times (ms) and accuracy rates (percentage) as outcome variables. Results of the first experiment have confirmed the hypothesis that the advantage of sharp-edged contour was obtained from both the accuracy and reaction time analysis. Also, random configurations were responded more accurately, as we had expected. However, main effect of configuration was not reflected on the reaction times. The second experiment was motivated to find the impact of high-level stimulus features by adding an incongruent contour type to smooth and regular configurations. Our results indicated

the advantage of sharp-edged contours and random configurations in crowded scenes for identification performance.

Keywords: visual crowding; contour integration; configuration; grouping; appearance

ÖZET

Görsel kalabalık, çevreleyici uyaranların varlığı nedeniyle hedef belirleme performansının zayıflamasını ifade eder. Görsel kalabalık çalışmaları çoğunlukla düşük seviyeli uyaran ortamları için sunulsa da yüzler ve konfigürasyon gibi yüksek seviyeli ortamlarda da gözlenmektedir. Bu çalışma, kalabalık sahnelerde kontur tipinin (keskin kenarlı-eğri kenarlı) ve konfigürasyon tipinin (rastgele-pürüzsüz) etkisini iki deney ile araştırmayı amaçlamaktadır. Hiyerarşik ve havuzlama modellerinin varsayımlarına dayanarak, keskin kenarlı konturların eğri kenarlı olanlara göre daha hızlı ve daha doğru tepki vereceğini varsaydık. Her iki modele göre, nesneler bir hiyerarşi izlenerek adım adım tanınır ve keskin kenarlı konturlar, basit çizgiler ve kesişim noktaları içermesi nedeniyle bir tanımlama avantajına sahip olabilir, ancak dairenin üçgenin sahip olduğu gibi belirgin bileşenleri yoktur. Ayrıca rastgele konfigürasyon denemelerinin, düzenli ve düzensiz olanlara kıyasla daha iyi sonuç oranlarına sahip olmasını beklenir çünkü gruplama, hedef ve çeldirici uyaranlar arasındaki benzerlikler nedeniyle hedefin tespitini zorlaştırabilir. Sırasıyla konfigürasyonu ve konturu kontrol ettiğimiz iki deney gerçekleştirdik. Sonuç değişkenleri olarak reaksiyon sürelerini (ms) ve doğruluk oranlarını (yüzdelik) karşılaştırdık. İlk deneyin sonuçları, keskin kenarlı kontur avantajının hem doğruluk hem de reaksiyon süresi analizinden elde edildiği hipotezini doğrulamıştır. Ayrıca, rastgele yapılandırmalar beklediğimiz gibi daha doğru yanıtlandı. Bununla birlikte, konfigürasyonun ana etkisi reaksiyon sürelerine yansımadı. İkinci deneyin motivasyonu, rastgele ve düzenli konfigürasyonlara uyumsuz bir kontur tipi ekleyerek yüksek seviyeli uyaran özelliklerinin etkisini bulmaktır. Sonuçlarımız, tanımlama performansı için kalabalık sahnelerde keskin kenarlı konturların ve rastgele konfigürasyonların avantajını göstermiştir.

Anahtar Kelimeler: görsel kalabalık; kontur entegrasyonu; konfigürasyon; gruplama; görünüm

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1. INTRODUCTION

Visual perception is a crucial mental process that involves and affects higher-order cognitive functions such as attention, memory, discrimination, and imagery. Thanks to this mental coordination of visual-cognitive functions (Cornsweet, 2012; Schneck, 2010; Bouska, Kauffman & Marcus, 1990), visual stimuli make sense to enable successful reading, writing, eating and even driving (Engel & Keizer, 2017; Nagayama, 1978; Kemeny & Panerai, 2003; Maeshima et al., 1997). According to the limited capacity of the human cognitive system, as in other sensory modalities, the visual system too has a limited capacity (Rosenholtz, 2017). Because of this limited capacity, for example, compared to Echoic memory, iconic memory has a larger capacity to store information with a shorter duration, while echoic memory has a smaller capacity with a more extended period capacity (Lu et al., 2005; Coltheart, 1980). As a function of the limited capacity, the visual system tries to deal with this bottleneck via some mental strategies such as chunking, clustering, and mnemonic devices, and one of the most well-known assumptions is the magical number 2±7, which reflects the amount of knowledge that can be kept in memory (Miller, 1956; Putnam, 2015; Paulo, Albuquerque & Bull, 2016; Gobet, 2001). There are lots of examples for this bottleneck, such as visual masking, temporal limitations and visual crowding, while these phenomena are all thought to be experienced as a result of this bottleneck (Kouider, & Dehaene, 2007; Gruber & Block, 2013; Thornton, Pinto, & Shiffrar, 1998; Whitney & Levi, 2011). These challenges might result from both limited capacity in time (temporal cost) and space (spatial cost). Former studies have investigated visual crowding via vernier – a task in which the offset between parallel lines is judged -, line and objects in different experimental paradigms, and they are mostly concentrated on low-level perspective and bottom-up processing (Sun &

Balas, 2015; Saarela, Westheimer & Herzog, 2010; Whitney & Levi, 2011). Nevertheless, this thesis is aimed to investigate the higher level configural aspect of visual crowding via investigating the low-level contour properties.

1.1. Visual Perception

Visual perception is thought to be one of the most crucial sense in humans and it is derived from the argument that visual perception enables individuals to monitor the environment, extract information and go into action regarding hierarchical perceptual processing (Bouska, Kauffman & Marcus, 1990; Lieberman, 1984; Schneck, 2010). By definition, visual perception is characterized as the prospering process between sensory information (reception) and cognitive functions of visual stimuli, so that perception as experiences resulting from the stimulation of the senses (Cornsweet, 2012; Haber & Hershenson, 1973; Lieberman, 1984). Successful communication and information transfer between sensation and perception are vital for functional visual processing. The sensory information is the first step of perceptual processing and it is responsible for achieving knowledge from the immediate environment; after which, cognitive functions enable processing sensory information via organizing and interpreting (Bouska, Kauffman & Marcus, 1990; Matlin & Foley, 1992; Coren, 2003). Through these two processes, a person can transfer sensory information to a higher-order cognitive system and comprehend the visual scene (Schneck, 2010; Bouska, Kauffman & Marcus, 1990).

Visual-perceptual skills are practical in almost every aspect of life, such as recognition of shapes, objects, and colors, and they are crucial for successful cognitive abilities (Corbetta et al., 1991; Arnheim, 1960; Cornsweet, 2012; Palmer, 1975; De Lange, Heilbron & Kok, 2018; Grill-Spector, 2003). Besides, visual

perception enables a person to make judgments and estimations about the given objects' size, depth, and configuration (Parker, 2007; Mitchison & Westheimer, 1984; Schwartz, 2009; Mennan, 2009; Navon, 1977). Furthermore, the importance of visual processing can be realized from the functional problems which might result from maladaptive visual perception (Uhlhaas et al., 2006; Huang et al., 2017; Paulesu, Danelli & Berlingeri, 2014). For example, dysfunctional visual processing might result in difficulties in eating, reading, writing, driving, and locating objects (Engel & Keizer, 2017; Bossert-Zaudig, 1991; Paulesu, Danelli & Berlingeri, 2014; Facoetti, Paganoni, & Lorusso, 2000; Gaab et al., 2007; Nagayama, 1978; Kemeny & Panerai, 2003; Forrest, 2004; Maeshima et al., 1997). In short, dysfunctional visual perception can cause severe problems in both daily life and in higher-order cognitive functions.

Thus, it goes without saying that visual perception is closely linked with vital cognitive functions, such as attention, memory, discrimination, learning.

1.1.1. Anatomy of the eye

When the anatomy of the eye is examined, one of the most important arguments is that the brain sees, not the eyes; eyes are only tools that send messages to the brain (Tavassoli, & Ringach, 2010; Schneck, 2010; Petit & Haxby, 1999). First, the eye transmits light to the retina, and visual receptors in the retina convert light into neural signals. These signals travel from the eye to the brain via optic nerves. The location at which the optic nerve leaves the eye is called a blindspot because no receptors (i.e., no rods and cones) exist at that location.

The receptive field is known as the area where the action of light changes the firing of the neuron. The receptive field also indicates the region of space that elicits an excitatory or inhibitory response from a given neuron. The retina is made up of

three distinct receptor nerve cells that include a light-activated chemical: cones, rods, and pupillary cells. Cones are responsible for color perception and visual acuity; rods are responsible for processing peripheral visual information; pupillary cells are responsible for controlling pupil dilation and constriction. Precisely, the fovea reflects the central vision and it determines the level of detail that can be perceived. Additionally, cones are highly concentrated in the fovea. However, rods are placed in the periphery of the retina, which is tuned to process peripheral information. After that, light passes through the cornea, and pupil size is determined by the iris, which is a component responsible for deciding how much light enters the eyes by increasing or decreasing the pupil size. To give an example, if the light is small, not so much light enters the eyes. The light then travels through a lens that provides focusing for near or far vision by vitreous humor.

1.1.2. Visual-cognitive functions

1.1.2.1. Visual attention

One of the visual perception skills is visual attention, which allows us to focus selectively on task-related information while ignoring irrelevant information or distractors (Chun & Wolfe, 2001; Schneck, 2010; Bundesen, 1996). This vital ability is also required to transmit visual information to the primary visual cortex so that functional visual perceptual processing can reveal in favor of selective visual attention. Thus, visual perception can work well through visual attention. Furthermore, visual attention is responsible for voluntary eye movements such as fixation and pursuit (Krauzlis, 2005; Thier & Ilg, 2005).

There are four interrelated components required for visual attention to occur: alertness, selective attention, visual vigilance, and shared attention (Oken, Salinsky &

Elsas, 2006; Chun & Wolfe, 2001; Schneck, 2010; Bundesen, 1996). Alertness is defined as arousal and an attentive state of arousal is required for adaptive actions such as learning, listening, and driving. The second component is visual vigilance, which is closely linked with the alertness component because it is defined as the voluntary mental effort to focus on a task. Moreover, selective attention refers to the ability to select relevant information while ignoring irrelevant ones. Like other components, selective attention is quite far from automatic processing and it requires a voluntary and conscious process. The last component is one of the complex elements of visual attention that is shared or divided attention. It is defined as the ability to respond to two or more tasks simultaneously. In general, one of the tasks is a kind of automatic process and uses fewer resources from the cognitive system. In contrast, the other is more demanding and requires more conscious effort. Owing to the four components, visual attention contributes to the mechanism of visual perception and there is a reciprocal relationship between them.

1.1.2.1.1. Covert and overt shift of attention

Visual attention enables individuals to selectively process relevant information via ignoring irrelevant ones (Schneck, 2010). In general, there are two types of vision with different limitations and resources: foveal vision - also known as the central vision – has referred to higher acuity around the gaze direction, whereas peripheral vision has reflected a wider field of view with lower resolution. In a similar vein, there are two different ways to attend peripheral visual field (De Haan, Morgan & Rorden, 2008; Findlay & Gilchrist, 2001; Hunt & Kingstone, 2003). If the head and eye movements are used to look directly at an object, it is called an overt shift of attention. However, attention can be preserved to the object without head and eye movements and it is known as a covert shift of attention.

Additionally, attention shifting has been divided into exogenous (externally driven) shifts of attention and endogenous (internally driven) shifts of attention (De Haan, Morgan & Rorden, 2008; Findlay & Gilchrist, 2001). Both covert and overt shifts of attention can be endogenous and exogenous, depending on the current situation. For example, eye movement towards an object that suddenly appears on the periphery is an example of an overt (exogenous) shift of attention. On the other hand, the voluntary decision to look at both mirrors in driving can be an overt (endogenous) shift of attention.

1.1.2.2. Visual memory

Visual information can conclude meaning with the aid of visual memory and there is an undeniable relationship between them (Phillips & Christie, 1977; Cowan, 2008; Parkin, 1999; Riou, Lesourd, Brunel & Versace, 2011). The main reason is that perception can change based on added information and visual information is integrated with past experiences by visual memory, so that perception is far from automatic. It involves complex processes as other visual-cognitive functions involved in visual perception.

In particular, there are three types of memory and this distinction is determined via their functions, durations, and capacities (Cowan, 2008; Parkin, 1999). First of all, long-term memory is known as a permanent storage system, and it has a huge capacity. In contrast, short-term memory has a limited capacity, which can hold a limited amount of information for a limited period of time. Short-term memory is not entirely distinct from working memory but the main difference between them is what they do with the given knowledge. Short-term memory is responsible only for holding given information for a short period, while working memory is tuned to manipulate, organize, and categorize it. For example, digits can be stored in short-

term memory, but clustering the digits or solving arithmetic problems can be carried via working memory.

An important argument summarizing the relationship between visual perception and memory assumes that our memory may result from our perceptual system (Riou, Lesourd, Brunel & Versace, 2011; Barsalou, L. W., 1999). Neuroimaging studies had supported this argument by showing that sensory-motor related brain areas were activated when participants respond to a memory task and showing that that sensory-motor activations are involved in the processing knowledge (Howard et al., 1998; Van Dantzig, Pecher, Zeelenberg & Barsalou, 2008). In other words, visual perception plays a role in the formation of memories and its processes contain sensory-motor functions so that it is reasonable to think that perception and memory share the same resources or have an overlapping mechanism. In the light of these assumptions, Riou and co-workers were aimed to investigate the impact of visual memory on a perceptual task (Riou, Lesourd, Brunel & Versace, 2011). They have manipulated the congruency between physical and perceived size difference in a visual search paradigm. As they have argued, congruency between typical and perceptual size differences caused faster response and incongruency has caused a cost in reaction time. Implications from the findings have revealed that visual memory and perception have shared mechanisms and it has demonstrated the link between visual memory and perception.

1.1.2.3. Visual discrimination

Visual perception skills also include visual discrimination, which is the ability to differentiate features between two or more stimuli (Mishkin, Ungerleider & Macko, 1983; Haxby et al., 1991; Gais, Plihal, Wagner & Born, 2000; Gulyas, 1994). Visual

discrimination allows us to recognize, match and categorize the given stimuli with the aid of long-term memory. These abilities require the ability to realize the similarities and differences between forms in order to relate these perceptual outcomes to previously stored information. Visual discrimination requires organization and categorization of a stimulus. A person with poor visual perception may not be able to discriminate between different shapes, colors, letters, numbers, or words that look similar.

1.1.2.3.1. Object (form) perception

As mentioned earlier, object vision can be the answer to the question 'what?' as it gives information about the visual stimulus characteristics such as color, size, and configuration (Haxby et al., 1991; Connor & Knierim, 2017). It was assumed in the literature that the two distinct neural systems mediate object perception: abstract visual form system (AVF) and specific visual form (SVF) and the main difference between both systems is whether the object is abstract or concrete (Gulyas, 1994; Haxby et al., 1991). The most critical condition for the AVF system to be activated is that the stimulus should be abstract and not to be specific. Moreover, the SVF system offers specific and concrete processing for a visual stimulus.

Moreover, object perception has crucial components that have an important place in the recognition process: form constancy, visual closure, and figure-ground recognition (Garje Mona et al., 2015; Brown, 2012; Visser et al., 2012). To explain form constancy, it refers to recognizing objects from different viewpoints, sizes and positions. This skill is substantial to have a consistency in object perception in the presence of changing environments. The second component is visual closure and it is defined as the ability to recognize objects with the lack of representations. Visual

closure skill requires to fill the gaps mentally and to be able to recognize the object. This skill depends on long-term memory because it needs to reach previously learned information to fill in the gap. For example, we can identify a cup that has been partly erased from its corners or edges via visual closure skills. The last skill to mention is the figure-ground recognition, which refers to the ability to differentiate between foreground and background. This skill is highly linked with the extraction of distracting information so that the process is tuned with the selective attention mechanism.

1.1.2.3.2. Spatial perception

It is vital to be aware of the location of objects to interacting with the environment as this is how we navigate the space accurately and communicate with the environment. Spatial vision is responsible for the location of the stimulus in space and it is the answer to the question 'where?' (Mishkin, Ungerleider & Macko, 1983; Haxby et al., 1991; Gulyas, 1994; Connor & Knierim, 2017; van der Ham et al., 2013). Spatial perception has substantial components that play a significant role in the location-based perception process (Connor & Knierim, 2017; van der Ham et al., 2013; Schneck, 2010). They are visual-spatial orientation, topographic orientation, and depth perception. The first component, visual-spatial orientation, is highly important for comprehending abstract concepts such as left, above, or down. Also, this skill enables us to perceive stimulus both in different orientations and versions. Secondly, we can perceive how far objects are from us via depth perception and it also aids moving in the space. The last component is topographic orientation and it is highly vital for location and route determination and wayfinding depends upon this skill. The reason for this is that cognitive maps consist of spatial information and they can be reached successfully via topographic perception.

In the literature, spatial relations are represented in two ways: categorical spatial relations and coordinate spatial relations. As in neural systems of object perception, the main difference between both of these relations is whether the location is abstract or concrete and there are both functional and neural differences between two relations. Categorical representations are mostly relevant with abstract concepts and their activation in the left parietal cortex is weaker compared to the coordinate representations (van der Ham et al., 2013; Mishkin, Ungerleider & Macko, 1983; Haxby et al., 1991). For example, right/left and above/below are the categorical representations. On the other hand, coordinate representations include precise and concrete relations and their activation in the right parietal cortex is relatively high (van der Ham et al., 2013; Mishkin, Ungerleider & Macko, 1983; Haxby et al., 1991). The accurate measurements of distance or size could be an example of the coordinate relations. As they function differently, neural signatures of two relations differ. Specifically, hemispheric processing is assumed to vary for both relations. The left hemisphere is thought to be mostly dominant for categorical representations, while coordinate representations are assumed to be processed via the right hemisphere. Besides, receptive field size is assumed to be related to the type of spatial representation. Specifically, coordinate representations are linked with large receptive field sizes, whereas smaller receptive field sizes are related to categorical spatial processing.

1.2. Visual Challenges and Bottleneck Phenomenon

1.2.1. Visual masking

1.2.1.1. Spatial limitation: masking

Visual perceptual skills have faced numerous challenges and limitations depending upon the narrow capacity of the human visual system. As with the other

sensory modalities, both visual and auditory systems have a limited capacity (Rosenholtz, 2017). As Miller had assumed, the magical number 2±7, which reflects the amount of knowledge, can be kept in memory (Miller, 1956; Putnam, 2015; Paulo, Albuquerque & Bull, 2016; Gobet, 2001). In comparison with echoic memory, iconic memory has a larger capacity to keep information with a shorter duration, whereas echoic memory has a smaller capacity with a longer period (Lu et al., 2005; Coltheart, 1980).

One of the challenges is visual masking, and it is one of the popularly studied tools in different research fields such as vision, memory, and linguistics (Hermens & Herzog, 2007; Dombrowe, Hermens, Francis & Herzog, 2009; Breitmeyer & Öğmen, 2006; Koelewijn et al., 2012). The target is preceded by a mask, which weakens the performance on the detection paradigm in visual masking. Additionally, visual masking is known as an attentional limit on both perception and memory due to the limited capacity of the human information processing system (Palmer, 1990; Breitmeyer & Öğmen, 2006; Koelewijn et al., 2012). Visual masking has a crucial role in both spatial and temporal dynamics of visual perception.

Specifically, there are two different types of visual masking termed as paracontrast (A-type) and metacontrast (B-type) (Breitmeyer & Öğmen, 2006). In A-type masking, the target and mask were presented simultaneously and they are temporally overlapped, while the presentation of the target and the mask have a delay in B-type masking so that the mask follows the target after a delay. Thus, the temporal dynamics of visual perception is mostly studied via metacontrast (B-type) masking.

The classical visual masking theories have assumed that A-type masking is stronger than B-type masking (Francis & Herzog, 2004; Breitmeyer & Öğmen, 2006;

Koelewijn et al., 2012). The main reason is that the mask and the target are temporally overlapped so that processing of the task and the interference of the performance have worked together at the same time frame, which might be related to the increased cognitive load. Contrary to the assumptions of the classical theories, opponents have demonstrated that performance might be strongly impaired via B-type masking rather than A-type, especially for a delay between 20 to 100 ms.

Furthermore, the target-mask energy ratio is often aided to detect what type of masking is used (Breitmeyer & Öğmen, 2006; Dombrowe, Hermens, Francis & Herzog, 2009). The term energy is defined as the output of the luminance and the duration of the target-mask relation so that it is called LT (luminance and time) energy. Also, energy can be defined as the characteristics of the target-mask relation such as size, duration, and contrast. Previous studies have shown that A-type masking is mostly composed of high-energy masks and low-energy targets. In comparison, B-type masking includes low-energy masks and high-energy targets (Breitmeyer & Öğmen, 2006).

Former studies regarding visual masking have mostly concentrated on low-level masking interactions, such as the target-mask energy ratio (Breitmeyer & Öğmen, 2006). On the other hand, Dombrowe and co-workers were motivated to examine both the impact of the luminance and the global spatial layout on the visual masking paradigm. They have provided a substantial link between spatial and temporal factors on visual perception (Dombrowe, Hermens, Francis & Herzog, 2009). The target was presented in the center, and participants were asked to indicate the direction of the vernier, whether left or right. The stimulus onset asynchronies (SOAs) were presented in six different onsets (0, 20, 40, 60, 80, 100 ms). The results

have implied that low-level properties of masking, such as luminance, is not enough to explain the masking mechanism because additional stimulus caused a diminished strength of visual masking. Besides, results have confirmed the hypothesis that grouping rules made the masking stronger for shorter SOAs, while the strength of masking was weaker for longer SOAs because temporal dynamics violated the perceptual rules. The overall implication from the findings is that both global spatial layout and low-level characteristics interact with each other, and both of them are substantial for the strength of visual masking.

1.2.1.2. Temporal limitations: masking

In addition to spatial limitations of visual masking, another restriction in which visual perception is facing depends on temporal factors. It is quite significant for a clear vision to balance temporally the upcoming visual information to reach a spatial and temporal flow of a scene or a moment (Wutz & Melcher, 2014; Rosenholtz, 2017). As in spatial limitations, temporal dynamics are challenging with the bottleneck problem depending upon the limited capacity of the cognitive system and temporal limitations are mostly dominated via time-related restrictions. Thus, the brain must give priority to some information while ignoring others via selective attention mechanisms and it creates a hierarchical temporal integration process. It can be clearly inferred from the assumptions that memory, attention, perception and sensation have interrelated and reciprocal relations.

Moreover, temporal limitations of visual perception can be divided into two distinct processing: seeing slow and seeing fast (Wutz & Melcher, 2014; Holcombe, 2009; Breitmeyer & Öğmen, 2006). Visual perception is created via the successful integration of the slow and fast groups. Also, in the light of the understanding of

temporal limits of visual perception, it is possible to comprehend temporal illusions. The fast group includes simple perceptual processing such as edges, depth, and direction, whereas the slow group is responsible for processing higher-order perceptual processing such as judgment and identification of visual qualifications (Holcombe, 2009; Breitmeyer & Öğmen, 2006).

Additionally, flicker perception is involved in the processing of seeing fast and it works based on visual qualifications such as luminance and contrast (Holcombe, 2009; Coltheart, 1980; Breitmeyer & Öğmen, 2006). Also, the limitation of seeing fast is approximately 50 Hz, and it has quite a faster temporal limit compared to the slow group. Specifically, coordination and integration of low-level visual stimulus properties and temporal factors can explain the reason for fastness. To give a few examples, integration masking might be a good example for a fast temporal limit because it contains a shorter delay, which requires fast seeing. Detection of color, orientation, simple edges and intersections also needs fast processing because they are low-level stimulus properties that can be detected faster. Furthermore, the visual system can create a global form via binding local elements, which is also considered as fast processing (Wutz & Melcher, 2014; Breitmeyer & Öğmen, 2006).

Contrary to fast temporal limits, the slow group is linked with higher-order cognitive processing and so that they need more time to be processed via the visual system (Holcombe, 2009; Breitmeyer & Öğmen, 2006; Vogel, Woodman & Luck, 2006). This slower group is thought to be related to selective attentional mechanisms because of the limited capacity of the information that can be kept in the visual system. Slower temporal limits can be clearly observed for word perception, motion perception and feature conjunctions.

1.2.2. Visual crowding

1.2.2.1. What is visual crowding?

Visual crowding –a phenomenon that describes degraded visual detection and discrimination of a target object when neighboring elements are presented– has been extensively studied in spatial vision, and it is considered an essential phenomenon for providing information to comprehend the mechanisms behind object recognition, discrimination and detection (Levi, 2008; Herzog et al., 2015; Livne & Sagi, 2007). Also, visual crowding provides substantial perspective for clinical interventions for patients with macular degeneration and dyslexia. Primarily, crowding is defined as the detrimental influence of nearby elements on peripherally presented target detection in a given visual field (Levi, 2008; Herzog et al., 2015; Pelli, 2008; Whitney & Levi, 2011). Although crowding studies mostly presented for low level stimulus settings, it is observed in high level settings as well such as faces, configuration and food (Husted, Banks & Seiss, 2012; Whitney & Levi, 2011; Livne & Sagi, 2007).

In particular, visual crowding occurs both in foveal and peripheral vision. It is observed over large distances in peripheral vision (0.5°), whereas small distances are enough to crowd foveal vision (Bouma, 1970; Toet & Levi, 1992). Moreover, visual crowding is not isotropic in the peripheral vision (Toet & Levi, 1992). It meant that horizontal arrangements of the stimulus are less damaging for performance and the strength of crowding is weaker compared to vertical arrangements of the stimulus, whereas the opposite is valid in the left visual field. Also, visual crowding is asymmetric, which means that the effect of crowding is stronger in the peripheral vision than in foveal vision (Bouma, 1973).

Like visual crowding, other phenomena too might cause degraded target detection in the visual field, such as masking, surround suppression, and lateral interaction (Pelli, Palomares & Majaj , 2004; Levi, 2008; Petrov, Popple & McKee, 2007). Even though these phenomena share similar outcomes, their neural mechanisms work quite differently. One of the challenges is to decide whether a specific paradigm is crowding or masking. As a solution for this problem, the critical spacing of visual crowding was suggested because only the visual crowding can be observed based on a distance criterion. Other phenomena are mostly mediated by the signal size or set size rather than the critical distance. Additionally, the inward-outward anisotropy only occurs in visual crowding and it was first discovered by Bouma (1973). According to Bouma's rule, a target might be detected faster and more accurately when stimuli are located within the inner region or closer to the fovea. Surprisingly, Bouma demonstrated that peripheral or outer stimuli had higher discrimination rates than inner stimuli and it is one of the unique characteristics that crowding has.

Furthermore, both crowding and masking degrades performance which motivated Levi and co-workers to find which one is more affective (Levi, Klein & Hariharan, 2002a). To test this hypothesis, they gave participants different versions of detection paradigms composed of Gabor features for crowding and masking. Results have indicated that the strength of crowding in the periphery was relatively higher than the strength of masking.

1.2.2.2. Critical distance (Bouma's law)

Visual crowding has differed from other similar paradigms such as masking and surround suppression via the critical spacing. The critical spacing was first

discovered via Bouma, and it has referred to as “the center-to-center separation of target and flankers” (Bouma, 1970). This is required for visual crowding to occur both in the foveal and peripheral vision because it was quantified depending upon the assumption that the full isolation of the visual stimulus is observed at an eccentricity of 0.5°. In other words, flankers can impair performance only when presented in a specific spacing interval. Specifically, Bouma’s law is a crucial determinant for visual crowding because previous studies have shown that stimulus size had no impact on peripheral vision performance whereas it is more likely to depend on the eccentricity (Livne & Sagi, 2007; Levi, Hariharan & Klein, 2002b).

1.2.2.3. Properties of visual crowding

1.2.2.3.1. Low-level characteristics of visual crowding

Visual crowding has been traditionally studied by concentrating on the low-level visual features of the stimulus such as orientation, size and color (Levi, Hariharan & Klein, 2002b; Levi, Klein & Aitsebaomo, 1985). Thus, it was mostly studied via simple paradigms such as lines, letters and verniers. The main reason was the assumption that visual crowding was thought to cause a main bottleneck for object perception, in general (see Section 1.3.). However, recent studies have stated that visual crowding is also observed in high-level stimulus settings and the recurrent processing is able to explain the underlying mechanisms of visual crowding rather than the classical low-level theories of object perception (Herzog, Sayim, Chicherov & Manassi, 2015; Levi, 2008).

1.2.2.3.2. High-level characteristics of visual crowding

1.2.2.3.2.1. Gestalt laws of grouping

As demonstrated by the relationship between the brain, eye and LGN, human beings have an extraordinary ability to organize information (Kaas, 2003). One of the pioneering theories of the perceptual organization is structuralism, which was initially proposed by Wilhelm Wundt in 1879; after that, this concept was revised and renamed by Max Wertheimer as Gestaltism (Wertheimer, 1912; Man & Vision, 1982). The most crucial argument of the theory has stated that "the whole is different than the sum of its parts". Thus, the perceptual organization is defined as an ability to organize local parts to reach the global picture and this is the fundamental assumption of the perceptual organization of the objects (Wagemans et al., 2012; Brooks, 2015). As can be understood from the definition, the similarities (grouping) and differences (violation of grouping) between the local elements are important for Gestalt principles of perceptual grouping.

To examine the principles, law of pragnanz (simplicity) states that every stimulus can be perceived as simple as possible so that it highlights the importance of parsimony in the perceptual organization (Wertheimer, 1912; Wagemans et al., 2012; Brooks, 2015). Good gestalt is also related to the law of pragnanz because goodness is referred to as the clear and simple configuration of the spatial layout. Besides, similarity law says that similar objects are more likely to be perceived as grouped. Law of similarity is one of the important mechanisms that the strength of visual crowding utilizes. As the similarity between target and flankers increases, the strength of crowding increases (Herzog, Sayim, Chicherov & Manassi, 2015). Moreover, when connected lines are presented together, they are more likely to be perceived as together and known as law of good continuity. The crucial thing here is that the lines must have a regular pathway to be perceived as belonging. Another important principle is the law of proximity and it supports that adjacent objects are likely to

perceived as grouped which also reminds us the importance of the critical distance in crowding (Bouma, 1970). In addition to non-static objects, the perceptual organization has also been detected in moving objects. The law of common fate says that as the objects move in the same direction, they are perceived together.

1.2.2.3.2.2. Grouping and crowding

One of the most critical factors required for visual crowding to occur is the application of similarity laws between the target and flankers so that the strength of crowding is highly moderated by the grouping principles (Herzog, Sayim, Chicherov & Manassi, 2015; Manassi, Sayim & Herzog, 2012; Manassi, Sayim & Herzog, 2013; Sayim & Cavanagh, 2013; Chung, Levi & Legge, 2001). Besides, the grouping is not only important for visual crowding, but it also plays a significant role in masking paradigms, haptic and auditory crowding (Overvliet & Sayim, 2013; Oberfeld & Stahn, 2012; Herzog & Fahle, 2002). In detail, grouping of target and flankers in terms of specific characteristics such as contour, orientation and spatial frequency increase the strength of crowding effect (Manassi, Sayim & Herzog, 2013; Malania, Herzog & Westheimer, 2007). On the other hand, as the target and flankers ungroup from each other in terms of length of the distractor, orientation or color, then crowding is weak and target detection becomes easier. That is the reason why understanding grouping principles is crucial for visual crowding. The role of grouping in crowding reflects a feature-specific characteristic of crowding.

Additionally, grouping mostly depends on the Gestalt principles such as similarity of target and flanker, Good gestalt, regularity and contour integration (Malania, Herzog & Westheimer, 2007; Manassi, Sayim & Herzog, 2012; Kooi et al., 1994; Livne & Sagi, 2007; Manassi, Sayim & Herzog, 2012). To give an example,

Saarela and colleagues were motivated to investigate the impact of Gestalt principles on the visual crowding paradigm (Saarela, Westheimer & Herzog, 2010). They manipulated target-flanker spacing and the effect of perceptual organization in terms of the regularity of spacing. Owing to this method, they have created a grouping principle and they investigated the effect of spacing via four conditions: tight, shifted, wide and added conditions. In the experiment phase, participants were asked to discriminate the orientation of the letter T.

Specifically, the spacing between target and flanker was very small and regular in the tight condition, that it led to grouping and caused the highest thresholds for participants. However, spacing was increased in shifted condition without creating any pattern, and it resulted in decreasing the crowding strength. On the other hand, the crowding strength was increased in wide condition even though the spacing was increased again because this time, a regular pattern was created via spacing regularity. In the last condition, more flankers were added between target and flankers so that the strength of crowding decreased again. To conclude, results have confirmed the hypothesis that grouping is key to understand the underlying mechanisms of visual crowding.

1.2.2.3.2.3. Configuration

The visual system, especially in the peripheral vision, has a tendency to bind single elements to form global pictures depending upon Gestalt laws (Levi, 2008; Livne & Sagi, 2007; Herzog, Sayim, Chicherov & Manassi, 2015). Besides, it was proposed that the strength of crowding could be determined only via investigating how the local and global elements are grouped with each other. The impact of configuration on visual crowding reflects the high-level representation of the

phenomena so that the inner/outer asymmetry was explained by the way that the outer one was more salient because it reflects the overall configuration (Banks, Larson & Prinzmetal, 1979; Levi, 2008).

For example, Livne and Sagi have investigated the influence of configuration on crowding by creating different configurations of Gabor patches (Livne & Sagi, 2007). In the experiment phase, participants were asked to judge the orientation of the Gabor patch. Internal arrangements of the configurations have differed as smooth and random contours. In the smooth configuration, Gabor patches were positioned to form a circle, and the target had a different orientation. Besides, this paradigm also reflected the contour integration principle of Gestalt laws because it compares the situations of whether flankers were grouped to make up a contour or not. Results of the orientation discrimination task had revealed that the strength of crowding was weaker when smooth configurations were presented and were increased when a random one was used.

Similar to the current study, Palmer has investigated the local and global impacts of perceiving objects in different configural distributions via three behavioral experiments (Palmer, 1980). In the experiments, participants were asked to indicate the orientation of the triangle, which they saw first by saying the number they saw in a clockwise direction surrounding the central triangle. Triangles were presented as axis-aligned, base-aligned, and combined configurations with different orientations. Also, circles and squares were added in the second and third experiments to investigate the impact of local counterparts. The first experimental results have revealed that as the triangles were positioned randomly, it was more likely to be perceived as in the same direction as consistency effect, which has confirmed the

hypothesis that configuration influences and creates a bias for the perception of local parts. Subsequent experiments aimed to detect global and local impacts of configurations via manipulating both distribution and contour of objects because if the global configuration overrides the local parts, it would not be influenced by the contours of local elements. The main aim of the using the circle was that they lack orientation and they are symmetrical along all axes. However, triangles and squares have corners and inherent orientational characteristics. Thus, they were more likely to be affected by the overall configuration. Results have shown that both triangles and squares had greater biases relative to circles toward up, down, left, and right. The reason for this might be that many vertical and horizontal lines can be observed in daily life. Also, the difference between triangles and squares was not significant in direct proportion with the expectations of the author. Overall results have confirmed the hypothesis that configuration influences and creates a bias for the perception of local parts, and not only configural or global aspect was notable, but also characteristics of local elements were crucial for the detection of objects.

1.2.2.4. Ecological validity of the visual crowding

1.2.2.4.1. Visual crowding and reading

Comprehension of visual crowding has highly contributed to the understanding of object perception both in normal and abnormal vision so that there are several implications from the phenomena: one of them is reading (Pelli, Palomares & Majaj, 2004). Previous studies have demonstrated that the critical space for visual crowding was equal to the critical space for reading (Levi, Song & Pelli, 2007; Pelli et al., 2007). Indeed, it was traditionally known that the size was crucial for reading rather than the spacing. To test this hypothesis, Levi and co-workers have examined the impact of size and spacing on the reading performance in both normal and

amblyopic vision (Levi, Song & Pelli, 2007). As they have expected, results showed that size did not influence the performance. In particular, as the spacing was increased in the text, reading becomes easier, so that visual crowding has reflected a limitation for reading.

1.2.2.4.1.1. Visual crowding and dyslexia

Dyslexia is characterized as a learning disability including reading and writing (Lorusso et al., 2004; Dautrich, 1993). Recent research has shown that phonological deficits are one of the fundamental reasons for reading difficulties. Interestingly, former studies have stated that people with dyslexia experienced less crowding in the periphery, while they had more crowding in the foveal vision (Geiger & Lettvin, 1987; Lorusso et al., 2004; Dautrich, 1993). Lorusso and co-workers have aimed to study the impact of reading difficulties on visual recognition performance (Lorusso et al., 2004). Participants were categorized as people with dyslexia, poor readers, and normal readers. Participants were presented a visual recognition task and they were asked to recognize target letter positioned whether in the peripheral or foveal vision. Interestingly, dyslexic and poor readers had significantly higher recognition rates than normal readers in the peripheral vision to the right side of fixation. Also, results were similar for the left side of fixation for all groups.

1.2.2.4.2. Visual crowding and driving

Visual crowding has been extensively studied on different low- and high-level features in vision science, whereas Xia and colleagues, for the first time, have demonstrated the impact of crowding in the natural driving situation (Xia et al., 2020). They have hypothesized that visual crowding would be strong in driving situations because there are many distractors, such as pedestrians and cars, in peripheral vision.

In the first experiment, they presented participants natural driving videos and participant's eye movements were recorded during the experiment. In the second experiment, participants were asked to discriminate the gender of the pedestrians. As hypothesized, for crowded condition, delays in saccadic localization and diminished behavioral performance implied that crowding occurred in natural driving situations. Overall results have stated that there was a huge impact of visual crowding on recognition in driving situations.

1.3. Object Perception Theories

1.3.1. Hierarchical and pooling models

The traditional vision literature has in common that crowding leads to a bottleneck for object perception and it worsens identification of any object or stimuli only in peripheral vision because of the limited capacity of the human vision system (Levi, 2008; Fischer & Whitney, 2011; Herzog & Manassi, 2015; Whitney & Levi, 2011; Hoot & Aronsky, 2008; Levi & Carney, 2009; Asplin et al., 2003). The idea of the bottleneck was derived from the pooling and hierarchical models that are attempting to describe the crowding mechanism based on the limited capacity between stages of perception and the theory of object recognition in a bottom-up manner. Pooling models represent step by step processing of object recognition, and it initially starts from low-level processing to high-level processing, which is known as bottom-up perception, as in the hierarchical models (Freeman & Simoncelli, 2011). The reason why pooling models state that crowding is a bottleneck or main limitation for the visual system is that if the information is lost on initial stages, this information is not retrievable at the more complicated stages.

Pooling and hierarchical models had argued that crowding was reflected better at early stages of processing on V1 and V2 because they consider crowding as a bottleneck (Chen et al., 2014; Kwon, Bao, Millin & Tjan, 2014; Millin, Arman, Chung & Tjan, 2013; Pelli, 2008; Anderson et al., 2012; Liu, Jiang, Sun & He, 2009). Nevertheless, it was shown that V4 represented crowding strength better due to its high-level characteristic (Chicherov, Plomp & Herzog, 2014).

On the other hand, recent studies have shown that pooling models and hierarchical models might be underestimating the crowding phenomenon as some features might not be visible and apparent to the observer because the brain gives priority to elements as a whole; thus, it causes invisibility of single components (Herzog & Manassi, 2015; Riesenhuber & Poggio, 1999, Herzog, Sayim, Chicherov & Manassi, 2015; Whitney & Levi, 2011; Herzog & Manassi, 2015; Banno & Saiki, 2012). These findings orient attention from early stages to later stages of processing, proposing that crowding is determined and influenced mostly by the final stages of processing and how the object looks (Dakin et al., 2011).

1.3.2. Recurrent processing

Recurrent processing is currently used more commonly for explaining crowding compared to pooling and hierarchical models (Adelson, 1993; Herzog, Sayim, Chicherov & Manassi, 2015). This model has acknowledged that low-level and high-level information interacts with each other during the processing of perception (Adelson, 1993). Unlike the importance of initial stages in the hierarchical models, the final stages of processing are a significant determinant for crowding, and it is the appearance of the object that reflects high-level visual information (Dakin et al., 2011).

Appearance is defined as how the stimuli look in terms of feature characteristics such as size, shape, orientation and configuration. For instance, if the appearance of any stimuli changes in terms of color, shape and length, crowding magnitude changes too (Dakin et al., 2011). Thus, this condition improves the effect of appearance on crowding. When recurrent processing and appearance were considered together, there are some shared points like the importance of final processing due to prioritizing the wholes. The appearance of the whole object comes first in time, while feature appearance comes next (Hochstein & Ahissar, 2002). For this reason, crowding is a kind of process reminiscent of seeing the forest instead of trees, as stated in Navon's assumption about global and local processing of information (1977).

1.4. Alternative Explanations of Visual Crowding

1.4.1. Aesthetic perception and preference

The low-level properties of the contour of an object are long known to affect aesthetic perception and preference (Silvia & Barona, 2009; Bar & Neta, 2006; Bar & Neta, 2007; Leder, Tinio & Bar, 2011; Palumbo et al., 2014; Gómez-Puerto, Munar & Nadal, 2016; Vartanian et al., 2013). Gordon and Lundholm's works, which are among the oldest studies, have shown that curved lines were felt to be more pleasant, whereas angular lines were associated with agitation and anger (Gordon; 1909; Lundholm, 1921).

Silvia and Barona have currently investigated whether people would prefer curved objects over angular objects or not with two behavioral experiments (Silvia & Barona, 2009). In their design, symmetry was controlled because there was a notable difference between curved and angular lines in terms of symmetry so that curved lines are symmetrical from all axes. In contrast, symmetry is quite limited for angular lines,

such as a rectangle is symmetrical along only horizontal and vertical axes. Thus, symmetrical objects and asymmetrical polygons were presented in the first and second experiment, respectively, and participants were asked to rate the objects from 1 to 9 due to liking. Also, the individual difference in art expertise was controlled via a self-report scale because it was assumed that this could affect aesthetic preference. As expected, angular hexagons were rated as less pleasing relative to circles in both experiments, regardless of whether they are symmetrical or not. Besides, people who got higher scores from the expertise scale were more likely to rate both contours equally. It might be stated that as the level of expertise goes up, the impact of angularity diminishes.

1.4.2. Evolutionary perspective

One of the explanations for the aesthetic preference of the contour was derived from the hypothesis that sharpness creates an inherent sense of threat and fear (Bar & Neta, 2006). To test this hypothesis, Bar and Neta have investigated the relation between angularity and threat perception via neuroimaging and behavioral studies (Bar & Neta, 2007). Everyday objects were presented to participants, both sharp-edged and curve-edged versions, and they were asked to decide whether they liked it or not. Also, mixed sharp-edged and curve-edged objects were given for a control condition, and emotionally neutral objects were chosen. Behavioral results have confirmed the hypothesis that curve-edged objects were liked more than both control and sharp-edged objects. Additionally, the neural basis of the sharp-edged contour has revealed that greater amygdala activation was observed for sharp-edged contours compared to curve-edged and mixed contour. Overall, these results provide the hypothesis that sharp-edged objects are preferred and liked less because they carry the perception of threat.

1.5. Aim of the Present Thesis

This thesis is designed to investigate and evaluate the effect of contour type and configuration of spatial layout on visual crowding. As mentioned above, many studies examined the role of configuration in isolation irrespective of the type of contour; no study examines the effect of both these aspects on crowding to our knowledge. The contour of objects was manipulated between sharp-edged (triangle) and curve-edged (circle), whereas the overall configuration changed between random, regular and irregular with a different combination in two experiments. The regularity of the configuration was determined due to the concurrency between local and global contours, which was an additional level specified to the second experiment. For example, when local triangles are positioned to form a large triangle, this is called a regular configuration. However, when they are positioned to form a circle this is an irregular configuration. Our research question is whether certain low-level or high-level aspects as controlled by altering contour and configuration respectively, have a dis/advantage to influence crowding magnitude differently. We hypothesized that the sharp-edged contour would be detected easier and faster compared to curve-edged ones. The reason why is that pooling models and hierarchical models had stated that recognition of objects start with the initial stage which processes the simple lines and it becomes higher-level in further analysis. A sharp-edged contour has a detection benefit because it is composed of lines compared to a curve-edged contour. We also expect that the detection of flankers would be more difficult in regular and irregular configurations than the random one since objects are grouped into smooth contours and flankers might be harder to detect according to Gestalt principles.

2. EXPERIMENT 1

2.1. Method

2.1.1. Participants

Thirty-one participants (n = 31, 6 female, 25 male) participated in the study. Both undergraduate and graduate participants have attended the study in Computational Neuroscience and Visual Perception Laboratory at Yeditepe University, and they were given course credit in return. Age of the participants ranged between 17 to 25 (*M = 19,68, SD = 2,166*). All participants had normal or corrected to normal vision. All experiments were approved by the Science-Ethics Committee of Yeditepe University.

2.1.2. Stimuli and apparatus

Visual detection paradigm which was created by PsychoPy Builder 3.0.0b11 version was run via computer. Participants were asked to follow instructions on the screen, and the distance between computer and participants was 60 centimetres. In the first experiment, contour and configuration were the independent variables, whereas reaction time and accuracy were the outcome variables. Specifically, contour had two levels as sharp-edged contour and curve-edged contour, while configuration was manipulated as regular or random. Target and flankers were either triangle, that used for the sharp-edged contour condition or circle, that was used for the curve-edged condition. The target and flankers were positioned on a circle, a triangle or on controlled random positions on the screen to create the sharp-edged, curve-edged or random configurations respectively. The first type of configuration is referred as smooth and the latter one as random. The computer screen had a grey background, while target, flankers and the fixation cross were white colored.

2.1.3. Procedure

The visual detection task was aimed to measure crowding magnitude among four experimental conditions (sharp-edged-smooth, sharp-edged-random, curve-edged-smooth, curve-edged-random). Participants were tested one by one. At the beginning of the experiment, participants were asked to read the instructions in the instruction screen, which were also replicated with verbal expression via experimenter prior to the session. In each stimulus screen there were 12 objects, where half of the shapes were located on the left and another half on the right side of the central fixation cross (Fig. 1). All objects within a stimulus screen were either triangles (sharp-edged) or circles (curve-edged) organized in different configurations. Both the equilateral triangle and the diameter of the circle were specified with a visual angle of 1 centimeter in the experiment. The target objects were indicated with a visual angle of 0.3 millimeters placed inside the flankers. Participants were sitting at a distance of 60 cm from the computer screen so that each stimulus subtended 0.5° of visual angle, and the stimuli were presented from 3° to 12°. The computer screen had a grey background, while target, flankers and the fixation cross were white colored. Participants were asked to fixate at the fixation cross during the experiment, and their task was to detect on which side does the target appear (right or left). They were asked to press ‘L’ if the flanker was on the right, and “D” if it was on the left for the sake of spatial correspondence between the stimulus and keyboard buttons. Once participants give a response, the screen disappears and the new trial arrives. Before the experiment, participants performed a practice trial which consisted of 12 trials. All conditions were randomly presented to the participants. The experiment lasted approximately 15 minutes. In total, there were four blocks and 480 trials. Those trials were randomized (counterbalanced) for all four conditions. Each stimulus was

presented for 1500 milliseconds and it was followed by a black fixation cross for 500 milliseconds which separates the trials from each other.

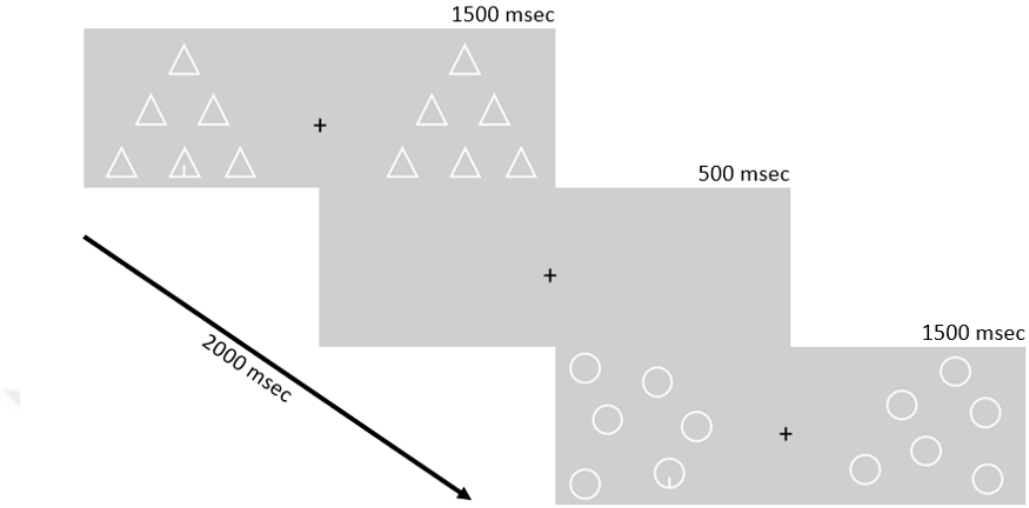

Figure 1. The Depiction of Array Design

Fig. 1. The typical sequence of trials in Experiment 1 and 2. Each stimulus was presented for 1500 milliseconds and it was followed by a black fixation cross for 500 milliseconds which separates the trials from each other. The target objects were placed inside one of the 12 flankers and participants were asked to indicate the position of the target (left or right) while they were fixating the cross.

2.1.4. Data analysis

Design of the study was 2 x 2 (sharp-edged-smooth, sharp-edged-random, curve-edged-smooth, curve-edged-random) within-subject factorial design. Repeated measures analysis of variance (ANOVA) was separately conducted for accuracy rates (percentage) and reaction times (ms).

2.2. Results

2.2.1. Accuracy analysis

According to the accuracy rate (percentage) analysis, Mauchly's test indicated that the assumption of Sphericity was violated, and the required assumptions were not meet so Greenhouse-Geisser estimates of Sphericity was used for correction. The results showed that there was a significant main effect of contour type on accuracy rates, $F(1, 27) = 35.221$, $p<.001$, partial $\eta^2 = .57$. Posthoc comparison via Bonferroni test indicated that sharp-edged trials ($M = .78$, $SE = .02$) were significantly responded more accurately compared to curve-edged trials ($M = .72$, $SE = .02$) (Fig. 2).

There was also a significant main effect of configuration type on accuracy rates (percentage), $F(1, 27) = 28.267$, $p<.001$, partial $\eta^2 = .51$. Posthoc comparison via Bonferroni test indicated that random configuration trials ($M = .77$, $SE = .02$) were responded significantly more accurately than smooth configuration trials ($M = .73$, $SE = .02$) (Fig. 2).

However, there was no interaction between contour and configuration on accuracy rates $F(1, 27) = .315$, $p=.58$, partial $\eta^2 = .01$.

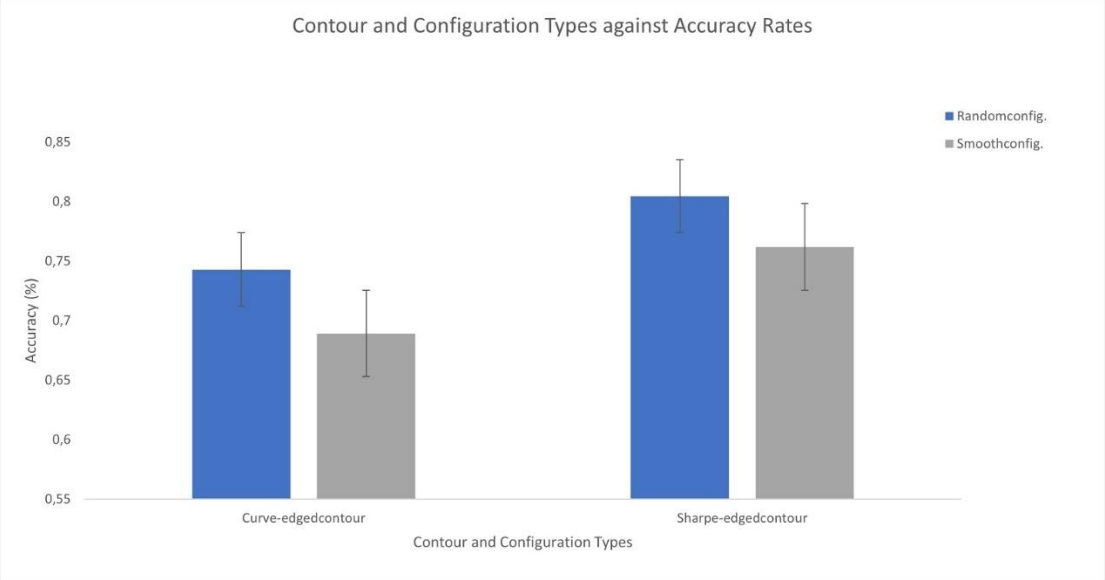

Figure 2. Contour and Configuration on Accuracy Rates (percentage)

2.2.2. Reaction time analysis

Two-way repeated-measures ANOVA was conducted with contour type (sharp-edged and curve-edged) and configuration type (random and smooth) as within-subject factors and reaction time (ms) and accuracy (percentage) as the dependent variables. For a more sensitive analysis, participants who performed with less than 60 percent of accuracy were excluded from the analysis; in total, three participants were outliers.

Analysis of two outcome variables was conducted separately. According to the reaction time (ms) analysis, Mauchly's test indicated that the assumption of Sphericity was violated, so Greenhouse-Geisser estimates of Sphericity was used for correction. The results showed that there was a significant main effect of contour type on reaction time, $F(1, 27) = 13.295$, $p=.001$, partial $\eta^2 = .33$. Posthoc comparison via Bonferroni test indicated that sharp-edged trials ($M = .642$, $SE = .01$) were responded significantly faster than curve-edged trials ($M = .654$, $SE = .01$) (Fig. 3).

However, the main effect of configuration on reaction time was not detected $F(1, 27) = 2.747$, $p=.11$, partial $\eta^2 = .01$, and there was no interaction effect between contour type and configuration on reaction time (ms) $F(1, 27) = .457$, $p=.51$, partial $\eta^2 = .02$.

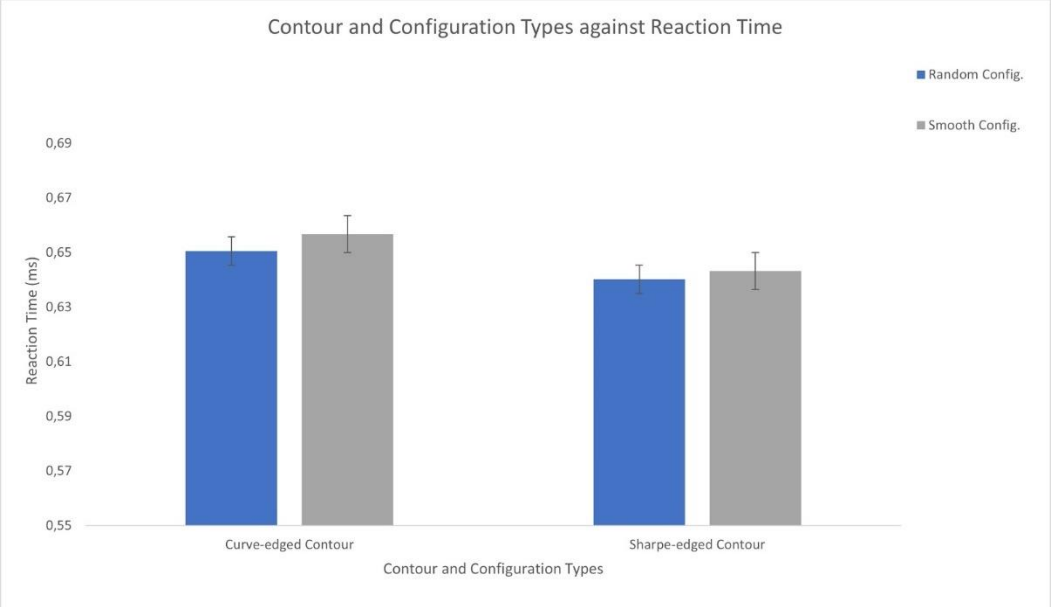

Figure 3. Contour and Configuration on Reaction Time (ms)

2.2.3. Target distance and relative position analysis

Within-subject ANOVA was conducted to estimate the global (eccentricity) and local (relative position within the sharp-edged configuration) distances on RT and accuracy. In the first analysis, the relative position of the target in the sharp-edged contour (edge, non-edge) was used as the independent variable and reaction time as the dependent variable. Levene's test indicated that underlying assumptions for homogeneity of variances have been met, $F(1,54) = .045$, $p = .833$. There was a significant main effect of position of the target in the sharp-edged contour on reaction time, $F(1,54) = 16.491$, $p < .001$. Specifically, the target was detected significantly faster in the non-edge condition ($M = .63$, $SE = .01$), compared to edge condition ($M = .69$, $SE = .01$) (Fig. 4). Secondly, a within-subject ANOVA was conducted with the position of the target in the sharp-edged contour (edge, non-edge) as independent variable and accuracy rate as a the dependent variable. There was a significant main effect of position of the target in the sharp-edged contour on accuracy rate, $F(1,54) = 47.300$, $p < .001$. Specifically, the target was detected significantly more accurately in

the non-edge positions (*M* = .82, *SE* = .03), compared to the edge positions (*M* = .58, *SE* = .02) (Fig. 5).

Pearson correlation was used to test the effect of target eccentricity on the results and the results indicated that there was a significant negative association between target distance and reaction time, r = -.106, n = 13440, p < .001. Similarly, a significant negative correlation was obtained from the association between target distance and accuracy, r = -.308, n = 13440, p < .001. These results implied that an increase in both accuracy and reaction time is related to the decrease in the target distance.

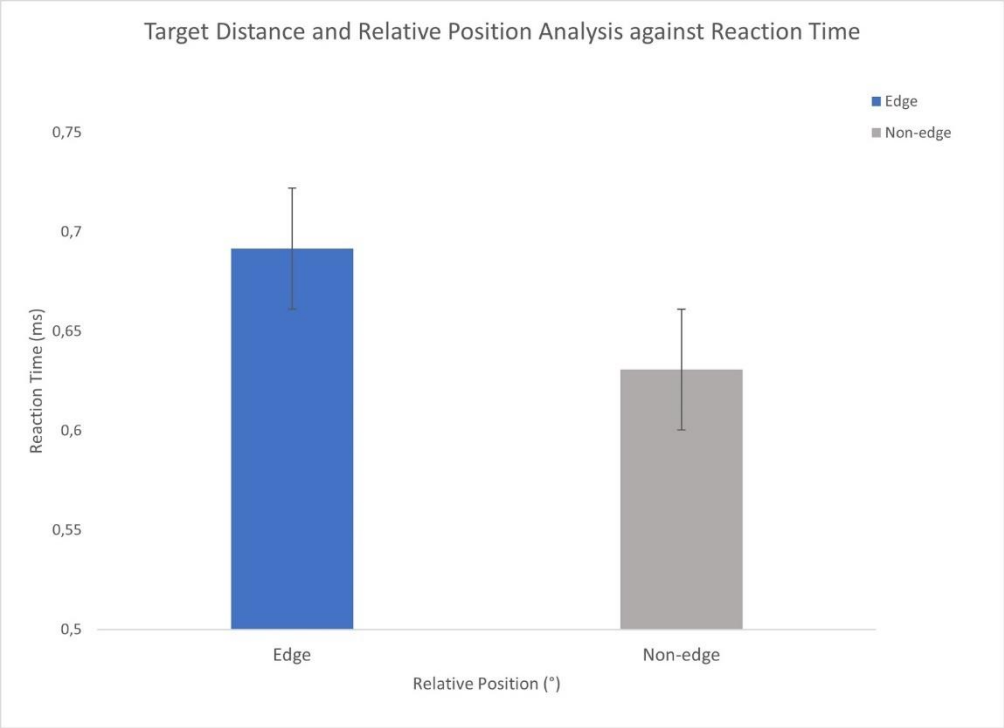

Figure 4. Target Position on Reaction Time (ms)

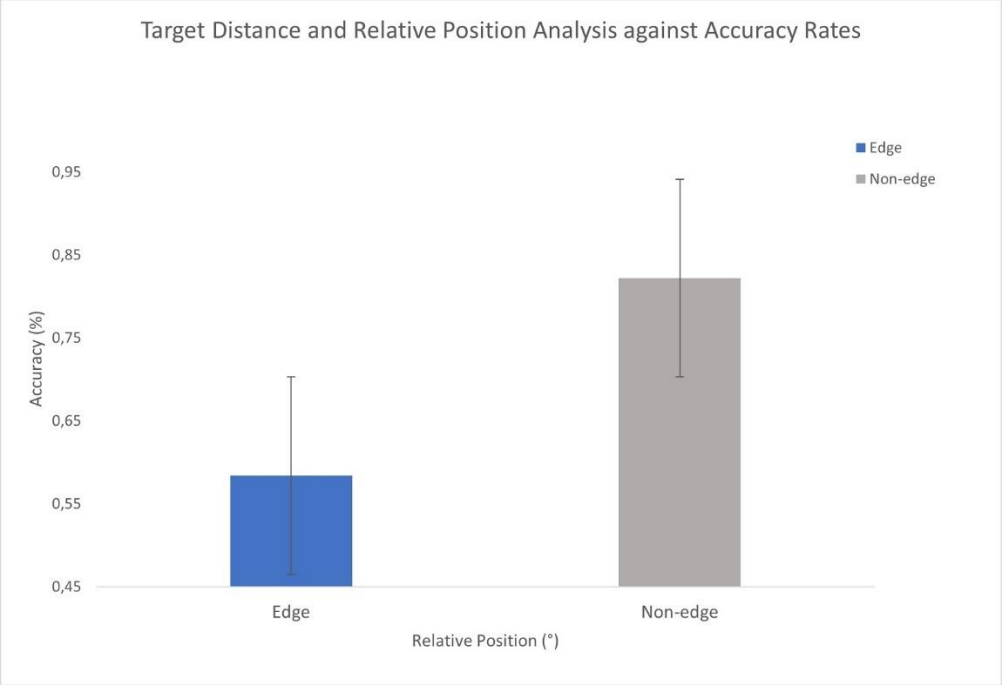

Figure 5. Target Position on Accuracy Rates (percentage)

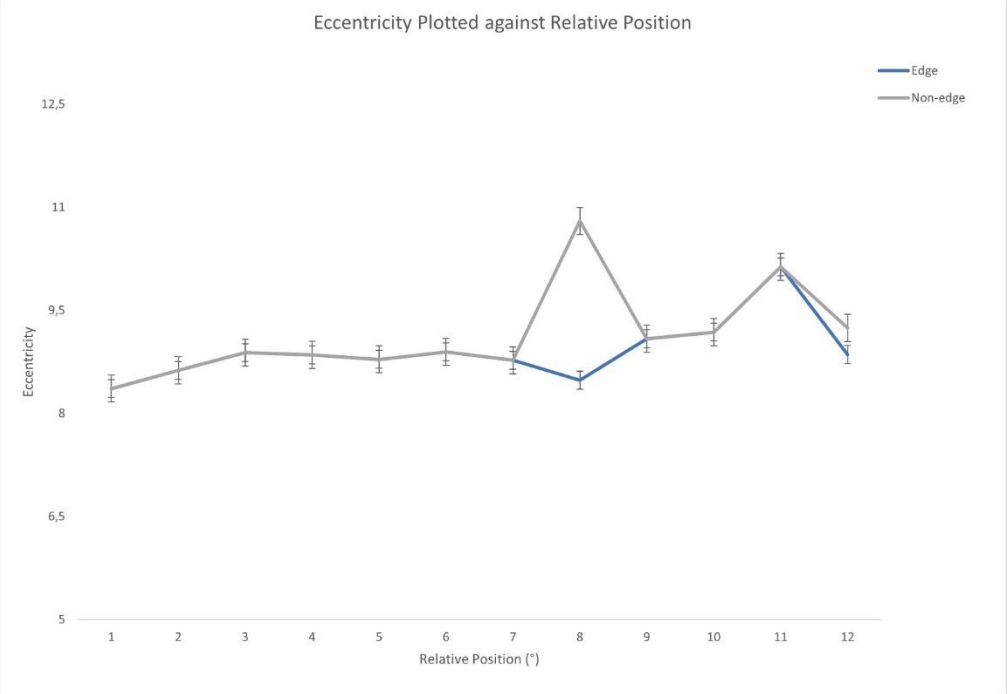

Figure 6. Eccentricity Plotted against Relative Position

2.3. Discussion

In the first experiment, we tested the effect of contour and configuration in a visual crowding task. The current study has revealed the main effect of contour and configuration on accuracy rate and the main effect of contour on reaction time. As

hypothesized, results have indicated that targets were detected faster when both target and flankers are sharp-edged objects and it was harder to detect the target when objects were placed in a smooth-edged holistic configuration. The results at first sight are consistent with the pooling and hierarchical models. According to those models, object recognition process starts with the low-level information processing and transferred to higher level areas at the proceeding levels of analysis, which is an example of data-driven processing (Freeman & Simoncelli, 2011). Here, target was recognized easier in sharp-edged contour conditions due to what those models assumed, that is sharp-edged objects have simple lines and edges compared to curve-edged ones.

Besides, configuration analysis has revealed that the target in a random configuration was responded quicker and more accurately than a smooth configuration. In the smooth configuration condition, there could be grouping between target and flankers because small objects were organized in a way to form a large object. Thus, the grouping may make it harder to detect targets whether it is in the periphery (Herzog et al., 2015).

Also, edge analysis has shown that when the target was not in the corner of the global triangle, it has created an advantage in both reaction times and accuracy rates. Because it could create an alternative explanation about the advantage of an edge over curve-edged contour, this had motivated us to investigate both types of contour within the same trial. Another purpose for the second experiment was to detect configural differences among mixed contours to see if the configural effects were intact when mixed contours are presented on each side.

3. EXPERIMENT 2

3.1. Method

3.1.1. Participants

Thirty participants (n = 30, 15 female, 15 male) participated in the study. Participants have attended the study in Computational Neuroscience and Visual Perception Laboratory at Yeditepe University, and they were given course credit in return. Age of the participants ranged between 18 to 38 (*M = 25,77, SD = 4,272*). All participants reported to have normal or corrected to normal vision. All experiments were approved by the Science-Ethics Committee of Yeditepe University.

3.1.2. Stimuli and apparatus

Similar to the first experiment, a visual detection paradigm was presented to participants and they were asked to follow instructions. The distance between the computer and participants was roughly 60 centimeters. Triangle was used as a sharp-edged contour and circle was used as a curve-edged contour. Their overall position on the screen was manipulated as random, regular or irregular. The computer screen had a grey background, while shapes and fixation cross were white colored.

3.1.3. Procedure

A procedure similar to the first experiment was applied in this experiment. In addition to the first experiment, a new level of configuration was added, and performance was evaluated across six experimental groups (sharp-edged-regular, sharp-edged-irregular, sharp-edged-random, curve-edged-regular, curve-edged-irregular, curve-edged-random). Each stimulus consisted of 12 objects, where half of the shapes were located on the left and the other half on the right of the central fixation cross (Fig. 7). One of the main differences between the two experiments is that objects were mixed within trials which consisted of both triangles (sharp-edged)

and circles (curve-edged) in this second experiment. All conditions were randomly presented. The experiment lasted approximately 10 minutes. In total, there were seven blocks and 504 (72 x 7) trials. Those trials were randomized for all six conditions. Participants were given 1500 milliseconds to respond and it was followed by a black fixation cross for 500 milliseconds which separates the trials from each other (Fig. 7). The rest of the details regarding the procedure was the same as the first experiment.

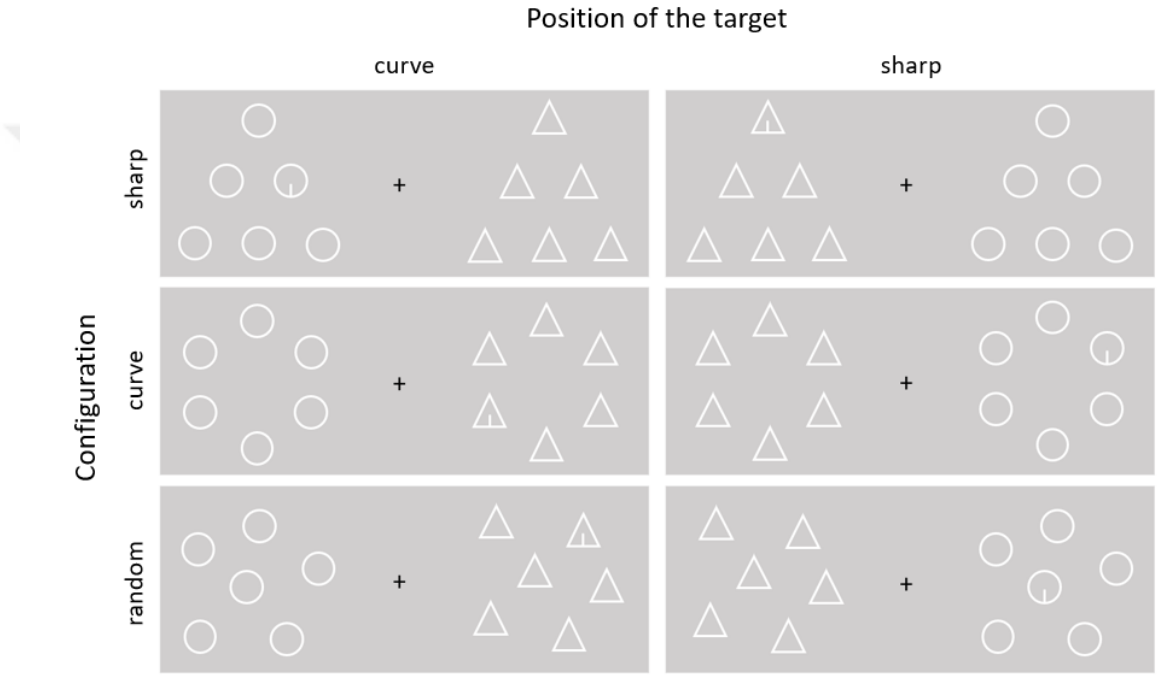

Figure 7. The Depiction of Array Design

3.1.4. Data analysis

The study was organized in a 2 x 3 (sharp-edged-regular, sharp-edged-irregular, sharp-edged-random, curve-edged-regular, curve-edged-irregular, curve-edged-random) within-subject factorial design. Repeated measures analysis of variance (ANOVA) was separately conducted for accuracy rates (percentage) and reaction times (ms). Exclusion criteria were performed for participants performing below 60 percent of accuracy rate, as in the first experiment.

3.2. Results

3.2.1. Accuracy analysis

According to the accuracy rate (percentage) analysis, Mauchly's test indicated that the assumption of Sphericity was violated, and the required assumptions were not met, so Greenhouse-Geisser estimate of Sphericity was used for correction. The results showed that there was a significant main effect of contour on accuracy rates, $F(1, 29) = 41.134$, $p<.001$, partial $\eta^2 = .59$. Posthoc comparison via Bonferroni test indicated that sharp-edged trials ($M = .81$, $SE = .02$) were responded significantly more accurately than curve-edged trials ($M = .69$, $SE = .02$) (Fig. 8).

There was also a significant main effect of configuration on accuracy rates, $F(2, 58) = 16.362$, $p<.001$, partial $\eta^2 = .36$. Like with the hypothesis, Posthoc comparison via Bonferroni test indicated that random configuration trials ($M = .78$, $SE = .02$) were responded significantly more accurately than curve-edged configuration trials ($M = .73$, $SE = .02$) and sharp-edged configuration trials ($M = .74$, $SE = .02$) (Fig. 8).

Additionally, There was no interaction between contour and configuration on accuracy rates, although a notable nonsignificant trend exists $F(2, 58) = 4.666$, $p=.068$, partial $\eta^2 = .18$.

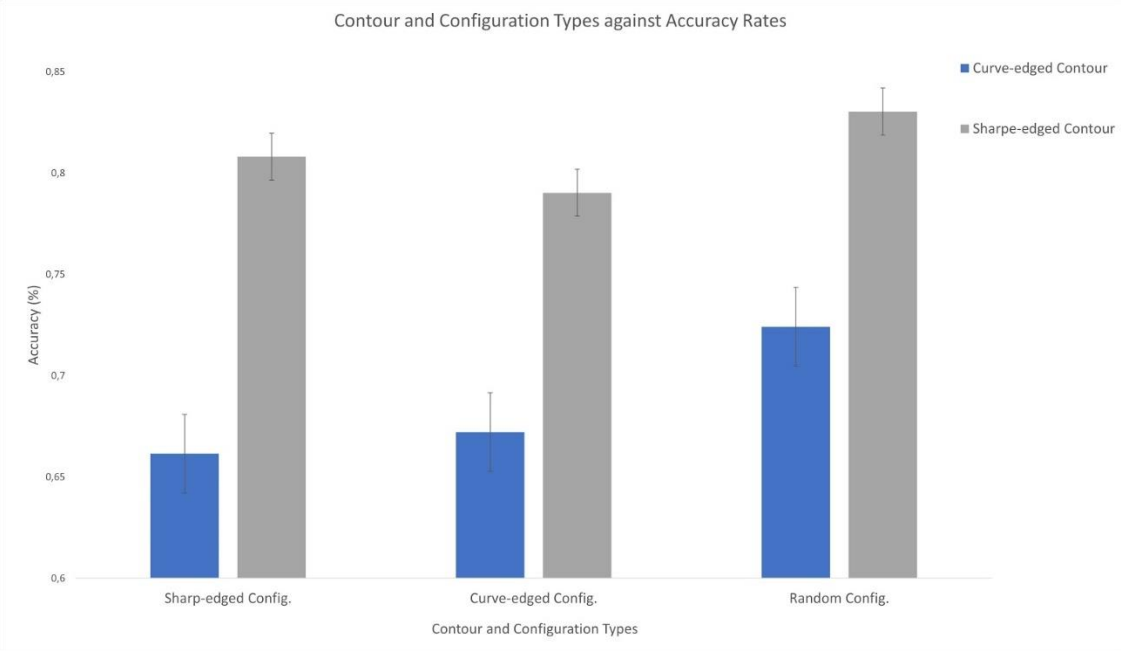

Figure 8. Contour and Configuration on Accuracy Rates (percentage)

3.2.2. Reaction time analysis

Two-way repeated-measures analysis of variance (ANOVA) was conducted to determine whether differences in reaction time (ms) and accuracy (percentage) were significantly different. Within-subject factors were contour (2 conditions: sharp-edged and curve-edged) and configuration (3 conditions: random, regular and irregular). Analysis of two outcome variables was conducted separately. According to the reaction time (ms) analysis, Mauchly's test indicated that the assumption of Sphericity was violated, thus Greenhouse-Geisser estimate of Sphericity was used for correction. The results showed that there was a significant main effect of contour on reaction time, $F(1, 29) = 34.243$, $p<.001$, partial $\eta^2 = .54$. Posthoc comparison via Bonferroni test indicated that sharp-edged trials ($M = 0.62$, $SE = 0.009$) were responded significantly faster than curve-edged trials ($M = 0.64$, $SE = 0.010$) (Fig. 9).

There was also a significant main effect of configuration on reaction time, $F(2, 58) = 6.457$, $p<.001$. Partial $\eta^2 = .18$. Posthoc comparison via Bonferroni test

indicated that random configuration trials (M = 0.628, SE = 0.010) and curve-edged configuration trials (M = 0.628, SE = 0.009) were responded significantly faster than sharp-edged configuration trials (M = 0.638, SE = 0.010) (Fig. 9).

There was no interaction between contour and configuration on reaction time, although there was a nonsignificant trend $F(2, 58) = 3.095$, $p=.073$, partial η^2 = .10.

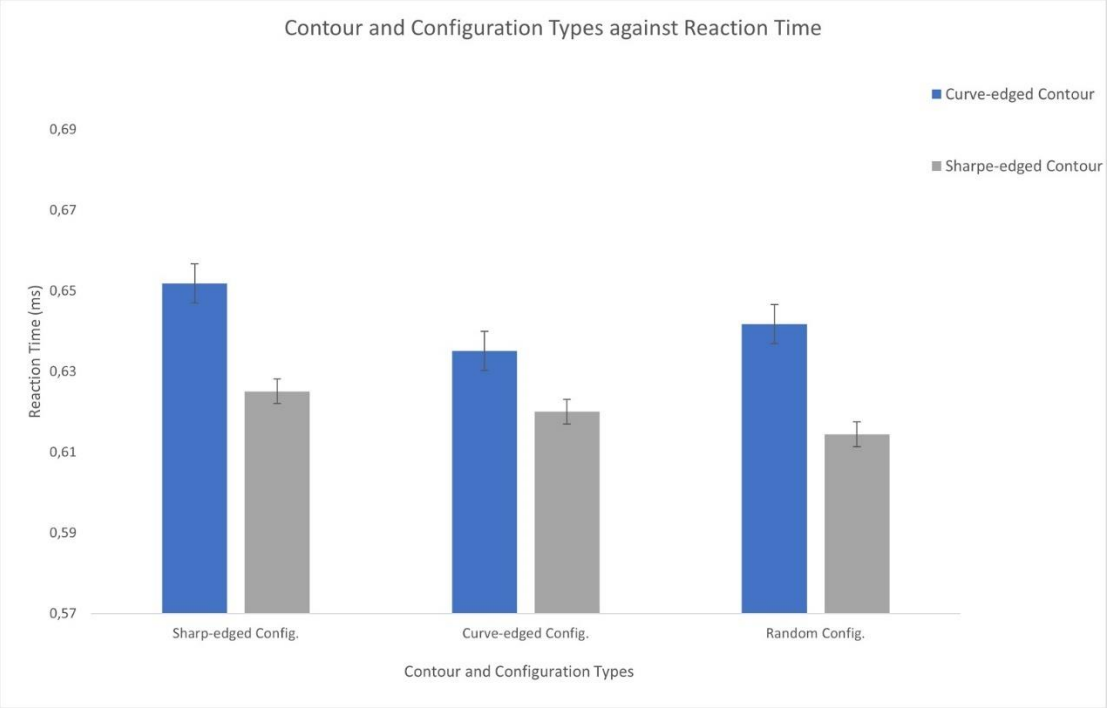

Figure 9. Contour and Configuration on Reaction Time (ms)

3.2.3. Target distance and relative position analysis

A within-subject ANOVA was conducted with the *relative* position type of the target (edge, non-edge) in the sharp-edged contour conditions as independent variables and accuracy rate as a dependent variable. There was a significant main effect of position of the target in the sharp-edged contour on accuracy rate, $F(1,58)$ = 4.535, p = .037. Specifically, the target was detected significantly more accurately in the non-edge condition (M = .84, SE = .02), compared to edge condition (M = .77, SE

= .03). However, a significant main effect of the edge was not obtained from reaction time analysis.

Besides, a within-subject ANOVA was conducted with configuration type (sharp-edged, curve-edged, random) as an independent variable and target distance (°) as a dependent variable. There was a significant main effect of configuration on target distance, $F(2, 87) = 71.044$, $p < .001$. Specifically, target distance in sharp-edged configuration ($M = 9.38$, $SE = .03$) was significantly greater than curve-edged configuration ($M = 9.01$, $SE = .04$) and random configuration ($M = 8.79$, $SE = .03$).

Pearson correlation was used to test the effect of target eccentricity on configuration and performance. The results indicated that there was a significant negative association between target distance and accuracy in random configuration, r = -.078, n = 5230, p < .001. Also, a significant positive correlation was obtained from the association between target distance and reaction time in random configuration, r = .098, n = 5230, p < .001.

3.3. Discussion

In the second experiment, we have added an incongruent configuration type to observe the effect of high-level features of visual crowding. As expected, random configurations were detected more accurately than both regular and irregular configurations due to the violation of grouping principles. The first substantive result that can be drawn from this study is the replication of the findings from the first study. The main effect of contour shows that sharp-edged objects are detected faster and more accurately than curve-edged ones regardless of being presented in a mixed or homogeneous contour setting. Also, adding an irregular configuration reveals that the main effect of configuration applies for both response variables. The interaction

between configuration and contour types revealed a prominent trend in the second experiment. It is important to note that the trials which tested each contour in all configuration settings and similarly, a configuration in all contour settings only existed in the experimental design of Experiment 2. Specifically, presenting both contours simultaneously put different combinations of contour and configurations in competition, revealing the main effect and interactions of each stimulus parameter. With this in mind, it is possible to contemplate that contour-configuration congruency reduces the crowding magnitude (Fig . 7).

As we have expected, the target in a random configuration is responded quicker and more accurately than (ir)regular ones whereas smooth configurations had similar reaction times, which will be criticized in the general discussion section. In addition, local position in sharp configuration was a significant factor in the accuracy results and it has again confirmed that the crowding magnitude is much higher for the objects presented at the corner position, as in the first experiment.

4. GENERAL DISCUSSION

The current study with two target detection paradigms has demonstrated that visual crowding was dramatically influenced by both contour and configuration, two factors that are known to be important for the strength of crowding. It has been previously reported that the peripheral crowding becomes stronger with laws of grouping and the use of agonic contour (Herzog et al., 2015; Manassi, Sayim & Herzog, 2012). In this study, we examined this concept by putting object contours and configuration of the overall scene in various compatibility levels. To do so, for instance in the sharp-edged configuration condition, small triangles are grouped to form a large triangle. One could suggest that this may increase the level of grouping and worsen the identification of the target, since target-flanker similarity increases the crowding magnitude.

In the first experiment, we found that there was a robust impact of contour and configuration on the accuracy rates and a main effect of contour on reaction time (see Discussion section of Experiment 1). With regard to configuration, trials with sharp-edged and random configurations were detected more accurately. Sharp-edged configurations were also responded to faster. Additional trials with a mixed contour design and contour-configuration incongruence in Experiment 2 showed that the significant main effect of both contour and configuration types were preserved with respect to both reaction time and accuracy. Despite the introduction of different contour-configuration incongruencies, randomly configured trials were responded to faster than smooth ones, indicating the dominant effect of the presence of smooth configurations in crowding. Our results showed that the congruency between contour and configuration types (i.e. the whole having the same shape as the individual objects) did not result in different crowding levels. In other words, it did not matter

for the measured outcomes what configuration the triangle objects have formed, but whether they follow a regular pattern or not. It is important to note that this could still be an effect that could not be observed as a behavioral outcome but at an attentional level and suggestions for these regards are revisited in the future studies section.

By far, the bias of grouping effect in crowding has been observed, which was created using smooth configurations. The grouping effect on visual crowding has been demonstrated by earlier studies where they took advantage of perceptual phenomena such as similarity and good Gestalt to create configurations (Banks & White, 1984; Herzog et al., 2015; Levi, 2008; Levi, 2009; Livne & Sagi, 2007; Livne & Sagi, 2011; Manassi, Sayim & Herzog, 2012; Sayim & Cavanagh, 2013; Whitney & Levi, 2011). When manipulations were made in configurations that violated grouping, better performance and decreased crowding magnitude was observed (Sayim & Cavanagh (2013). Similarly, using random configurations increased the target identification performance in the present study, where the grouping rule is violated. Likewise, in Herzog and Manassi (2015) authors proposed that the number of elements that causes grouping in overall configuration is a stronger determiner of crowding in comparison to the low-level local interactions between target and flankers (2015). In the present study, even the effect of eccentricity, –one of the most crucial factors influencing crowding– could be canceled out with a strong grouping effect (Exp. 2 - Discussion). Although prior studies confirmed the configuration effect on crowding using low level visual objects such as Vernier and Gabors (Manassi, Sayim & Herzog, 2012; Livne & Sagi, 2011), we have not come across any studies that look into the effect of systematic variation of configuration and contour simultaneously.

It is important to note that our results apply when target-flanker identities have low entropy. One alternative finding showed that random configurations can reveal high crowding amplitudes when the target-flanker identities highly vary, causing 'competency' between target and flanker recognition, which can also be explained by the saliency hypothesis (Livne and Sagi, 2007).

Contrary to our expectation, sharp-edged configurations were detected slower than random and curve-edged configurations. The advantage of a sharp-edged object was only present when used as a contour, in other words, on a local level. This has reflected a contour specific property for sharp-edged forms. In other words, the sharp-edged form revealed an advantageous performance when used as a contour (the local - facilitative) but decreased performance when used as the configuration (global - inhibitory). The advantage of sharp contour was not affected by the crowding performance. This is because the configuration effect is affected by high-level modulations in the visual cortex and influenced by the way the object is positioned rather than its contour. We can infer that the global perception created by sharp and curve-edged objects similarly increases the strength of crowding and grouping.

4.1. How can characteristics of circle and triangle be associated with crowding?

For the different shapes that were used in the experiment, the triangle and circle sit in the same area (i.e. length of the triangles and the diameter of the circles were the same) whereas a circle takes up more space – precisely 1.8 times more than the triangles. One can argue that this can affect the present results, whereas recent studies showed that bigger items can be easier to detect and to lead less crowding (Banks, Larson & Prinzmetal, 1979; Banks & White, 1984; Manassi, Sayim & Herzog, 2012). On the other hand, Levi and Carney tested this hypothesis by controlling the effect of Gabor size with distance and number of flankers in a discrimination task and they

have concluded that the distance, not the size or number of the flankers, was a crucial determinant for the strength of crowding (2009). Regardless, if occupied physical space was a deterministic attribute on performance, curve-edged contours (circle) would reveal less crowding magnitude compared to sharp-edged (triangle) conditions, while this was not the case in the present study no matter what type of configuration was used.

While the center of the large shapes that constitute the configuration was equally distant from the fixation, average eccentricity of the target and the flankers on either visual hemisphere were also different in for different configurations (curve configuration 9,01, sharp configuration 9,38, random configuration 8,78). The eccentricity was greater for sharp-edged configurations than curve-edged and random configurations. This might have caused a possible consequence of the condition with smallest overall eccentricity to reveal less crowding strength, however the average eccentricity in random configuration was the smallest, crowding strength was weakest in this condition, too. Due to the faulty integration model, when the size or number of the stimuli in a given display increased, crowding strength increased too. In line with current findings, increased number of flankers resulted in increased crowding strength due to the pooling models, and the reason was more information pooled in the human visual system which causes a bottleneck for information processing (Herzog & Manassi, 2015).

4.2. Conclusion

Contrary to studies that have defended only the hierarchical and pooling models of object recognition (object recognition theories), the present findings have supported both pooling models and recurrent processing (Adelson, 1993; Whitney & Levi, 2011; Wilkinson, Wilson & Ellemberg, 1997). Manipulating the contour of the

objects has enabled us to investigate both models because we were able to change both appearance and detection hierarchy. According to the recurrent processing, the appearance of the object which was the contour in the current study is vital for object recognition and, contour has a dramatic impact on both reaction time and accuracy rate regardless of configuration (Hochstein & Ahissar, 2002). Also, identification advantage of sharp-edged contours has indicated the validity of the pooling and hierarchical models. Thus, high-level and low-level interaction occurred during target detection in crowded stimuli as suggested by earlier studies (Dakin et al., 2011).

The advantage of sharp-edged contours and random configurations in object recognition and visual crowding has been demonstrated. It can be stated that the overall regular configuration of the visual stimulus makes crowding stronger. The current study has clearly shown that global and local coherence is not necessary to create a regular configuration. To create a regular configuration, the global and local features may not necessarily be the same, that is, if the contours of local and global objects are different, they can also create a regular configuration. What contributed to the crowding most was the regularity of the configuration.

4.3. Limitation

The main limitation of the study is fixation. Participants were asked to fixate at the fixation point during the whole experiment. However, it can be guaranteed only by giving verbal instructions to the participants. It is an obvious point that fixating center during the experiment could not be fully controlled without any tracking method because verbal expression cannot be fully safe. This is a critical point because when participants are not fixated at the center, it is straightforward to detect the side of the flanker whether at right or left. Also, the effect of crowding, as explained above, could be observed only peripheral vision in healthy participants. So, this study

can be replicated by using eye-tracking methods both in healthy and people with visual impairments (macular degeneration), enabling experimenters to use only really fixated trials to analyze, and results may be more reliable interpretable.

4.4. Future Studies

In the second experiment, behavioral results - both accuracy and reaction time analyses – have revealed that any difference existed between regular and irregular configurations. It was reasonable to expect a strong grouping and crowding effect from regular configurations compared to irregular ones where the global and local elements are the same. However, incompetency exists between items in the irregular configurations. A question arises from this situation whether irregular configurations are driven by bottom-up processing or whether we have to integrate the local items to see the big picture in irregular configurations? This might be due to the low sensitivity of behavioral measures so that neural signatures of configuration might be reflected better via neuroimaging techniques to detect high-level features.

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APPENDIX A: ETHICAL APPROVAL FORM

Gönüllü Katılım Formu

Öncelikle çalışmamızda denek olarak yer aldığınız için teşekkürler. **Dr. Ögr. Üyesi Funda Yıldırım** danışmanlığında Bilişsel Bilimler yüksek lisans öğrencisi **Elif Memiş** tarafından yapılan bu çalışma, görsel uyaranların algısı ile ilgili mekanizmaların anlaşılmasını amaçlamaktadır. Çalışmaya toplam 30 gönüllü alınacaktır ve çalışma on dakika sürecektir.
Sizi davet ettiğimiz araştırmada, görsel uyaranlara klavye tuşları aracılığıyla verdiğiniz yanıtları değerlendirerek bu uyaranları nasıl algıladığınızı araştıracağız.

Çalışmada insanların görsel uyarıların ne tür etkenlere bağlı olarak fark edildiğini anlamak adına hedef olarak tanımlanan çentikleri tespit etmeleri beklenmektedir.

Deneyde gösterilecek olan görsel uyaranların her biri 1 saniye kadar sunulacaktır ve bu sırada katılımcıdan ortada bulunan fiksasyon noktasına odaklanırken hangi tarafta çentik olduğunu klavyedeki tuşlardan biriyle belirtmesi istenecektir.

Seans boyunca katılımcıdan o anda görmekte olduğu uyaranların içinde herhangi bir objenin çentiği olup olmadığının fark edilmesi beklenecektir. Eğer çentiği olan obje sol tarafta tespit edildiyse klavyede ‘d’, sağ tarafta tespit edildi ise klavyede ‘l’ tuşuna basılması beklenecektir.

Deney süresince katılımcılar birer saniyelik toplam 480 denemeye maruz kalmışlardır ve her bir denemede katılımcılara sağ ve solda toplam 12 obje sunulmaktadır.

Size ait her türlü bilgi gizli tutulacaktır, yayın ve raporlarda kimlik bilgileriniz kullanılmayacaktır.

Çalışmaya bir kez katılacaksınız. Katılım sırasında herhangi bir nedenden ötürü kendinizi rahatsız hissederseniz, deneyi istediğiniz safhada bırakmakta serbestsiniz. Böyle bir durumda deneyi uygulayan kişiye, deneyi tamamlamayacağınızı söylemeniz yeterli olacaktır.

Çalışma veya kendi haklarınızla ilgili daha fazla bilgi almak için Bilgisayar Mühendisliği öğretim üyesi Funda Yıldırım

Bilgilendirilmiş Gönüllü Olur Formundaki tüm açıklamaları okudum. Bana, yukarıda konusu ve amacı belirtilen araştırma ile ilgili yazılı ve sözlü açıklama aşağıda adı belirtilen araştırmacı tarafından yapıldı. Araştırmaya gönüllü olarak katıldığımı, istediğim zaman gerekçeli veya gerekçesiz olarak hiçbir yaptırıma maruz kalmadan araştırmadan ayrılabileceğimi ve kendi isteğime bakılmaksızın araştırmacı tarafından araştırma dışı bırakılabileceğimi biliyorum.

Söz konusu araştırmaya, hiçbir baskı ve zorlama olmaksızın kendi rızamla katılmayı kabul ediyorum.

Gönüllünün;

Adı Soyadı:

Cinsiyeti: Tarih:

Adresi: Telefonu:

Yaşı: İmzası:

Araştırma Ekibinde Yer Alan ve Yetkin Araştırmacının;

Adı Soyadı:

İmzası: Tarih:

Adresi: Telefonu: