AN EXPERIMENTAL INVESTIGATION OF CHANGE BLINDNESS BY GROUP EYE TRACKING PARADIGM

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AN EXPERIMENTAL INVESTIGATION OF CHANGE BLINDNESS BY GROUP EYE TRACKING PARADIGM

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ABSTRACT

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The group effect refers to a decline in vigilance when an individual is in a social, group setting. Due to a diluted risk of being preyed upon and a higher number of group members that can detect a predator, members are less alert when they are in a group. The present study investigates if such an effect can be observed in human participants in a simple change detection task by employing group eye tracking (GET) paradigm. For this end, the visual phenomenon of change blindness is explored. In a within-subjects experiment, participants attempted to find if a change has been made to a stimulus they have previously seen. The same task was performed twice, once alone and once in a group of three while their eye movements were recorded with an eye tracker. Results of eye movement analysis show that, during the visual search for a change, eye movements are significantly slower when the participants are in groups (p < .01). The findings indicate that this effect may be related to a decline in vigilance and the group effect.

Keywords: vigilance, group effect, social cognition, change blindness, eye tracking

ÖZ

DEĞİŞİM KÖRLÜĞÜNÜN GRUP GÖZ İZLEME PARADİGMASINDA DENEYSEL ARAŞTIRMASI

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Grup etkisi, uyarana karşı tetiktelik durumunun (tetiktelik) birey sosyal bir grup ortamında bulunduğunda azalması anlamına gelir. Avlanılma riskinin azalması ve grupta bir yırtıcıyı saptayabilecek daha fazla üye olması sebebiyle, grup halinde canlılar daha az dikkatli olur. Bu çalışma, Grup Göz İzleme paradigmasını kullanarak, böylesi bir etkiyi insan katılımcılarla ve basit bir değişiklik saptama deneyinde gözlemlemeye çalışmaktadır. Bu amaçla, değişim körlüğü olgusu araştırılmıştır. Denek-içi bir deney tasarımında, denekler daha önce gördükleri görsel bir uyaranda değişiklik olup olmadığını bulmaya çalışmıştır. Aynı deneyi bir kez tek başlarına, bir kez de üç kişilik bir grup halinde tamamlayan katılımcıların göz hareketleri göz izleme ile kayıt edilmiştir. Göz hareketleri analizinin sonucu, değişikliği arayan katılımcıların göz hareketlerinin grup içindeyken anlamlı derecede daha yavaş olduğunu ortaya koymuştur ($p<.01$). Bulgular bu etkinin grup etkisi ve tetiktelikteki bir düşüşle ilişkili olabileceğini göstermektedir.

Anahtar sözcükler: tetiktelik, grup etkisi, sosyal biliş, değişim körlüğü, göz izleme

To my family, husband and cats…

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LIST OF ABBREVIATIONS

GET	Group Eye Tracking
METU	Middle East Technical University
TÜBİTAK	Scientific and Technological Research Council of Turkey
px	pixel
ms	milliseconds
PC	Personal Computer
API	Application Programming Interface
AOI	Area of Interest
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1. Purpose of the Study

Humans have evolved to forage in groups, and as a result they constructed the social and interactive environment of conspecifics that we experience today. This state of social interaction and dependence on others has allowed social cognition to emerge as a domain of research, suggesting that cognition can be dependent on social conditions that the individual experiences.

How being in a social and interactive group setting affects cognitive processes and perception has been a topic of social cognition for decades (Nye & Brower, 1996). One of the effects of being in a group on cognition is the *group size effect,* which is also the effect that the present study will mostly focus on. The group size effect (henceforth, the *group effect*) can be defined as a declined effort in being *vigilant* when the individual is in a group. It is suggested to consist of two factors; 1) declined individual risk of being hunted by a predator when in a large group and 2) more individuals to detect possible threats and dangers in the environment (Lima, 1995). In combination, these two factors allow individuals to spend less time and effort being alert and more time to other activities such as feeding, reproducing or resting.

The present study aims to contribute to the research of social cognition and more specifically vigilance and the group effect by investigating these phenomena in a systematic experimental paradigm. To this end, we are aiming to observe if there are any physiological indicators of a declined vigilance when human participants are in a group setting. Within this framework, we will be defining vigilance as a state of alertness, as well as the ability and willingness to detect any changes in the stimuli (Sternberg, 2009; Warm, Parasuraman, & Matthews, 2008). In order to observe the effects of group on detection, the present thesis will implement a change detection task and explore if the visual perception event of change blindness can be associated with a decline in vigilance. Moreover, since one of the main mechanisms underlying detection is vision (Beauchamp, 2015; Mackworth, Kaplan, & Metlay, 1964), the present study expects to observe the group effect in eye movements. As the group effect was primarily defined as a decrease in vigilance and alertness, slower eye movements will be considered as an indicator of declined vigilance within the framework of the present study.

Using eye tracking technologies, eye movements of the participants will be analyzed in the experimental research reported by the present study.

1.2. Research Questions and Hypotheses

In order investigate whether the group effect can be observed in human participants in a change blindness task, the research questions were formulated around the physiological responses and performance of the participants. What is referred to in this context as physiological aspects are eye movements, which we believe constitutes a significant part of human information extraction processes. The performance, on the other hand, will be measured in the form of accuracy and amount of correct answers in the change blindness task. To this end, a within-subjects, eye tracking experiment was employed in the present study. In this experiment, the participants completed the same change detection task under two experimental conditions: in the *Single Setting* condition, on their own, and in the *Group Setting* condition, in a group of three people. Within this context, we consider the following research questions:

(1) Is group effect observable in human participants in a change blindness task? In other words, does vigilance decline in groups in the given change detection task?

(2) Does the group effect influence physiological responses such as eye movements, and if so, how?

(3) Is change blindness more likely to occur when people are in groups?

Starting from these research questions three hypotheses were formulated. Firstly, in a more general sense we hypothesize that group effect will be observed in the Group Setting condition of the experiment and participants will have declined vigilance in this condition (H1). The second hypothesis of the present study (H2) is regarding eye movements, it is expected that a decline in vigilance in line with the group effect can be measured through physiological responses and will be translated into slower eye movements in the change detection task. Therefore, the hypothesis is that the eye movements of participants in the group condition will be slower. And finally, we hypothesize that a similar effect could be observable in performance measurements as well; that change blindness would be more prevalent in groups. The expectation is that the participants will have a lower probability of detecting a change when they are in a group and their accuracy ratings will be lower in the group condition of the experiment design (H3). These hypotheses are listed as follows:

H1: Group effect will be present in groups of participants attending a change blindness experiment in the form of declined vigilance.

H2: Eye movements of participants will be slower when they are completing the change detection in a group of three people.

H3: The participants will have lower accuracy ratings in the change detection task when they are in the group condition of the experiment.

1.3. Organization

The following chapter of the present thesis (Chapter 2) will lay out a theoretical and practical literature review on four topics that are related to the research questions; social cognition, vigilance, change blindness and eye tracking. Studies and experimental findings from these fields of research will be presented along with possible connections between them. In Chapter 3, information regarding the experimental research reported in the present thesis will be explained and the results and analysis of the experiment will be given in Chapter 4. Finally, Chapter 5 will provide a discussion regarding the results and whether the hypotheses of the present study were supported.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a literature review on the topics that are highly related to the goal and hypotheses of this study. First of all, social cognition will be covered in this chapter. The scope of literature review on social cognition will be mostly focusing on and limited to group interactions, since this subtopic is related more to the aims and hypotheses of the present thesis work. Secondly, this chapter will also include the phenomenon of vigilance, once again with a focus on social group settings. These two topics will be constituting the main theoretical background of the present thesis and the evolutionary approach that will be taken.

For the practical and experimental aspects, the visual perception phenomena of change blindness, as well as the implications it might have over social cognition and vigilance in groups will be discussed in this chapter as well. Findings and results of various studies from different areas of research are presented here. Within this framework, the goal is to lay out the theoretical and practical approach of the present thesis by proposing a possible connection between these various areas of research. Finally, the last section of this chapter will be covering the theory and applications of eye tracking, the primary mode of data collection in the experiment design of the present study.

2.1. Social Cognition in Groups

In a general sense, social cognition is a research domain that investigates interactions and cognitive processes in a social setting of multiple members (Nye & Brower, 1996). The mechanism behind social cognition is suggested to be gain-based and survival related, since a group of conspecifics can mostly outperform the individual in various domains (Frith & Frith, 2012). More specifically, how knowledge is stored and shared deliberately and non-deliberately among group members and how this affects survival chances and cognitive mechanisms of various species are some of the focal points of social cognition.

Social cognition has been associated to many cognitive systems and mechanisms. One of those systems is language. One study, for example, has explored social knowledge in baboons in comparison to human languages. In suggesting that language and grammar has emerged in evolution of pre-existing cognitive mechanisms like social knowledge, this study has attributed the development and evolution of language to social cognition (Seyfarth, Cheney, & Bergman, 2005).

Another study has also suggested that certain linguistic categories and grammatical structures can be speculated to have a direct relation to social cognition (Semin & Fiedler, 1988). The pre-existing cognitive mechanisms Seyfarth, Cheney and Bergman (2005) referred to in their study is representational thinking and categorical perception. These mechanisms have been suggested to be in effect in systems other than language as well, specifically in the context of how social cognition affects humans' perception of other humans (Macrae & Bodenhausen, 2000). Fiske and Taylor (1991) have also defined social cognition in a very similar manner, regarding how people perceive themselves and others in their book, *Social Cognition.*

Decision making and problem solving were also associated to social cognition in studies from various researchers. One study has investigated groups as a problem solving unit and suggested that identifying and conceptualizing the problem, and acquiring, storing and using the information about it were affected by being in a social, interactive group (Larson & Christensen, 1993). Similarly, it was shown that decision making was also associated to social cognition, with an emphasis of successful decision making being dependent on skills such as empathy and theory of mind (Frith & Singer, 2008). Moreover, social cognition has been associated to issues such as culture, social identity (Hogg, Abrams, Otten, & Hinkle, 2004) and even domestication of animals in relation to their social cognition skills (Hare, Brown, Williamson, & Tomasello, 2002).

Finally, one of the findings of social cognition is the phenomenon of social gaze, or how gaze locations and movements are affected cognitively and neurologically in social situations. (Frith & Frith, 2012). It is suggested that social gaze is indicative of joint attention. Moreover, being able to identify head and eye positions, encoding another individual's gaze direction and differentiating between direct and averted gaze are crucial to other cognitive processes such as theory of mind and learning (Frischen, Bayliss, & Tipper, 2007). As for the context of group behaviors, being in a larger group has been shown to affect speed and workload of learning, both in humans and other primates, and social gaze is an important part of this process (Emery, 2000). While social gaze will not be explored to its fullest in the present study, it is known that gaze can be affected in group settings. Therefore, for the experimental research of the present study, eye tracking was used as the primary mode of data collection in order to investigate how gaze behaviors of humans were affected by being in a group.

Moreover, in the experimental studies reported in the present thesis, both individual and group setting conditions were employed in order to investigate if certain cognitive and physiological mechanisms functioned differently between individuals when they were on their own and when they were in a social, interactive group setting. Therefore, among the research topics involved in social cognition studies, the present study will be focusing on group behaviors. In this context, *group* is used to define a social setting of multiple interacting individuals. However, a critical discussion when it comes to social cognition and group behaviors is how many individuals are needed in a group to be able to observe behavioral and cognitive differences. One answer to this question can be found in the Minimal Group Member Paradigm. It has been shown that two individuals (also called a "dyad") do not affect the behaviors of each other significantly. In other words, one member of a dyad does not pay enough attention to the actions of the other to show cognitive differences. However, when there are three individuals in a group, it is seen that this number is enough for a member to be behaviorally affected by the other two (Tajfel, Billig, & Bundy, 1972). The results of this study suggest that a group of three members is very significantly different than the dyad; therefore, it is suggestive of three members as a critical, minimal point for group cognition and behavioral patterns. In preparation of the experimental design involved in the present thesis, the Minimal Group Member Paradigm was employed and Group Setting experiments were conducted with the participation of three people (see Section 3.3).

Even after discussing what constitutes a group and how being in a group affects cognitive processes of each individual within it, another critical question arises. That is, why humans and some animals choose to forage in groups? One specific and evolutionary that the present thesis will be considering, is the decreased probability of being hunted by predators. Even though experimental research is scarce, some studies have suggested that as the group size increases two effects become significant: 1) the risk of being preyed upon by a predator decreases for each single individual and 2) the probability of detecting a predator increases in a group when compared to an alone individual (Elgar, 1989). It is also believed that this effect ties closely to the context of vigilance in group settings, which will be discussed in the next section. The present thesis aims to explore social cognition further by investigating how social cognition affects vigilance of individuals when they are in group settings.

2.2. Vigilance in Groups

Vigilance, in broad terms, can be defined as a state of alertness and a continued awareness of one's environment that usually can be seen as sensory monitoring of surroundings for possible threats and dangers. While the internal state of vigilance itself may not be easy to observe, various outcomes of it and changes in behavior can be seen when a threat is noticed (Beauchamp, 2015). In animals, vigilance can translate to an interruption to other activities in order to scan their surroundings (Beauchamp, 2008) but for humans, and more specifically in psychology, vigilance is used to refer to a sustained and concentrated state of attention towards surroundings and the ability and willingness to detect presented stimulus (Holland, 1958; Sternberg, 2009; Warm et al., 2008).

Neurological studies regarding vigilance have found a relation between vigilance and amygdala and shown that activation in amygdala can be associated to an increase in attention and arousal, enhancing sensory abilities as a result (Davis & Whalen, 2001; Sternberg, 2009). While there is quite possibly a neurological aspect to the phenomenon of vigilance, the present study focusses on eye movements, therefore using eye tracking as the primary mean of data collection, instead of brain imaging methods.

It is known that there are various factors that can affect and interfere with how vigilance functions. For example, age and stress has been shown to affect vigilance (Deaton & Parasuraman, 1993). It is also known that vigilance is a demanding cognitive process that increases work load (Warm et al., 2008), therefore multi-tasking with other activities that require a similar workload or sleeping may hinder processes of vigilant behavior (Beauchamp, 2015). Moreover, even breathing carbon monoxide has been associated with decreased levels of vigilance (Horvath, Dahms, & Hanlon, 1971).

Rather than these individual factors that may affect vigilance, the present thesis will focus mainly on how being in a group affects an individual's levels of vigilance and consider the *group size effect* to this end. Group size effect is a negative relation between levels of anti-predatory vigilance and number of members in a group. It has been observed in various studies that vigilance tends to decrease when group size increases (Lima, 1995). This effect was observed primarily in birds (Beauchamp, 2008; Griesser, 2003) and mammals (Michelena & Deneubourg, 2011) and then in humans (Dunbar, Cornah, Daly, & Bowyer, 2002) and fish (Freeman & Grossman, 1992; Magurran & Pitcher, 1987).

Since in a larger group there are more possible targets for a predator, the risk of one single individual being preyed on decreases. An awareness of this decreased probability can be one of the explanations for the group size effect. This effect is usually referred to as the *dilution effect* (Delm, 1990; Roberts, 1996). However, a more common explanation is the "*many eyes hypothesis"* or the *"collective detection effect"*, which suggests that as the size of the group increases, the number of eyes (and other sensory organs) in it increase as well. The task of detecting a predator and scanning for threat is distributed among the group, and not the responsibility of just one individual. Therefore one individual can spend less time for vigilance and more time for other activities like feeding, without any increase to their own probability of being hunted by a predator (Beauchamp, 2008, 2017; Delm, 1990). Most researchers consider the group size effect to be a combination of both the *dilution* and *collective detection* effects, but it is not yet clear which of these two mechanisms have a larger part.

Various studies have shown that individual factors contribute to levels of vigilance and the ability to adjust to group size effect. One of the factors that is quite effective in determining how fast individuals can adapt to increasing number of members within the group is gender. For example, an animal study conducted on pheasants (a type of bird), demonstrates that group size effect is more prevalent in female pheasants, vigilance decreased as the number of female pheasants increased. Male pheasants, on the contrary, demonstrated increasing levels of vigilance as the number of female pheasants increased (Whiteside, Langley, & Madden, 2016). A similar effect of difference between male and female members of a group was also observed in mammals as well. However in a study with elks, the effect was the opposite of pheasants; with female members being less affected by the group size effect (Childress & Lung, 2003).

In a more different framework, it was already mentioned in the previous section (2.1) that gaze could be affected by social interaction and groups. Similarly, some studies have intended to form a connection between gaze and vigilance as well. One study, for example, has linked eye movements to vigilance by reporting that eye movements and especially fixations were related to participants noticing and reporting stimulus (Mackworth et al., 1964). Another study has defined vigilance as the ability of noticing infrequent changes and has observed eye movements during a vigilance task. Their results show that individuals with higher rates of eye movements were more vigilant during the task (Schroeder & Holland, 1968). Both these studies suggest that eye movements are directly linked to alertness and indicates vigilance in participants. Even though these studies have investigated the relation of vigilance and eye movements, there are not any studies that explores the *group effect* specifically in relation to eye movements. The present study intends to explore the relation between the group effect and gaze, as well as vigilance.

As was mentioned above, the effect of individual factors such as gender and age has led the researchers to suggest that there is not an "*optimal number of members*" for group size effect, but rather the negative relation between size and levels of vigilant behavior (Beauchamp, 2015). Therefore, in the present study, individual factors will not be considered as an underlying mechanism of decrease in vigilance, but the experimental research involved will focus predominantly on the group size effect itself. Moreover, since vigilance was defined primarily as the alertness and awareness of surroundings, as well as detection, the present study has chosen to simplify a seemingly very complex mechanism by employing a task of change detection and exploring change blindness in social group contexts to this end.

2.3. Change Blindness

Change blindness is a visual perception phenomenon that can be defined as a failure to notice a change that occurs in the full visual field of the agent (O'Regan, 2006). While it is not yet possible to pinpoint one simple explanation and reason as to why change blindness occurs, some mechanisms have been suggested to this end. Three main explanations that are related to different cognitive mechanisms will be presented here.

First explanation is related to limitations in short term memory and is that it is possible that the agent does not have the ability to store and access to an internal representation of the unchanged environment. Even if the agent possesses a clear representation of the environment, it may not be detailed or coherent enough to seamlessly detect a change that occurs within it (Rensink, O'Regan, & Clark, 2000). Secondly, the agent may have an internal representation of the environment but fails to recall that representation. Therefore, once again the agent fails to compare two states, without having access to one of them. This explanation was developed in relation with attentional shifts and a selective processing of information. Since the environment is so crowded with various types of stimuli that processing all of it proves chaotic, rather than beneficial; it is suggested that the mind has evolved to selectively shift the attention to what is necessary (Simons & Levin, 1997). Finally, researchers have focused on knowingly eliminating conditions where the aforementioned two explanations hold. However the results show that even when an internal representation of the environment is present and can be recalled, change blindness can still occur (Simons, Chabris, & Schnur, 2002). Accordingly, it is suggested that change blindness is not only related to failure to store or recall a previous state of the world; but also, to the failure of comparing pre- and post-change states of the stimulus. Any one of these effects or a combination of all of them can be the mechanism that constitutes and causes change blindness.

On a more practical level, it is known that disruptions in the stimuli can cause change blindness and this information has been widely implemented in experimental studies concerning this phenomenon (Simons & Ambinder, 2005; Simons & Levin, 1997). What is referred to here as disruptions, are generally hindrances or interruptions to agent's field of view that occur simultaneously with a change in the stimulus. As to why disruptions can cause change blindness, two possible explanations are suggested. First, it is possible that noticing a change requires the shift of attention to the location of the change itself. Rensink (2001) suggests that in a natural environment, a change is likely the only occurrence that creates a motion signal, rendering it relatively easier to perform the necessary attentional shift. With disruptions, however, that motion signal can be confused and the agent cannot place or notice the change. An alternative explanation is that disruptions in the stimuli cause discrete breaks in an otherwise continuous flow of visual information, as given in a study that compares human olfactory system to visual perception and change blindness (Sela & Sobel, 2010). Moreover, similar effects have been observed in studies concerning other sensory mechanisms. For example, temporal breaks in information have been observed to cause failure to notice changes in auditory and tactile awareness scenarios as well (Gallace, Tan, & Spence, 2006). Within this framework, it is possible to conclude that continuity of information is a crucial element when it comes to change detection.

While disruptions in change blindness research serve a similar purpose in all mentioned experiments, there are various ways that this effect can be implemented. One way of implementing disruptions in a change blindness experiment is in the form of local disruptions. Local disruptions are feats of imagery that hinder or block a specific part or parts of the stimulus from the view of the agent. It is usually expected that these blocked areas are not covering where the change will be made (O'Regan, 2006). One common method that local disruptions are implemented is the form of mud splashes, which is a similar visual effect to that of mud splashing to the windshield of a vehicle (O'Regan, Rensink, & Clark, 1999). An example flow of such an implementation would be as follows; pre-change version of the stimulus appears on the screen, after a while the mud splash effect is introduced and blocks various areas of that image for a short period of time. And when the mud splashes disappear and blocked areas are visible again, a change has been made to the image.

More commonly used in change blindness experiments, however, is global disruptions (O'Regan, 2006). Similar to local disruptions, global disruptions also hinder or block the participant's visual field. However, instead of blocking a part or parts of the image, the entire image is blocked from the view. There are certain ways global disruptions can be implemented in change blindness experiments. One of them is the *flicker paradigm*, where a short flickering effect is introduced between the pre- and post-change images (Rensink, 2005). Within the experiment flow, the stimulus runs back and forth between unchanged and changed images with a short blank screen in between every one of them, creating the flicker.

Instead of the aforementioned disruption methods, such as mud splashes or the flicker paradigm that are widely used in change blindness research, the present thesis will focus on eye movements, more specifically saccades, in the experimental design of the change blindness task. It has been shown by previous studies that blinks and saccades can also act as global disruptions that cause change blindness, with effects that are rather similar to those of the flicker paradigm (O'Regan, 2006; Rensink, 2001; Rensink et al., 2000). An experimental study on change blindness, for example, has found that human participants' reaction times to detecting changes were significantly slower when blinks and saccades occurred 75 milliseconds before or 150 milliseconds after the change (Johns, Crowley, Chapman, Tucker, & Hocking, 2009).

The mechanism behind blinks and saccades causing change blindness and affecting reaction times when it comes to change detection tasks is rather similar to other methods of local and global disruptions in the stimuli. In the case of blinking, since the eyes do not have access to visual data while eyelids are closed, a similar trend of causing temporal breaks to the continuous flow of visual information is the possible mechanism in causing change blindness (O'Regan, Deubel, Clark, & Rensink, 2000). Saccades, on the other hand, are jerk like rapid eye movements that function as jumps between phases of fixations (Krauzlis, 2005). Even though the eyelids are open, it is suggested that no new or continuous visual information is processed during saccadic eye movements, but rather a few elements from the previous fixation are carried over (Rensink et al., 2000). And therefore, change blindness can occur during saccades as well (Bridgemen, Hendry, & Stark, 1975).

The main purpose of using a change detection task and exploring the phenomenon of change blindness in the experiment design was to identify whether the *group size effect* explained in Vigilance section (2.2) could be observed on a physiological level in a detection task. To this end, a slowing and latency of a physiological reflex such as eye movements was expected from the participants that attended the experiment. Therefore, eye tracking was used in the experiment sessions in order to collect data of eye movements and compare eye movements of participants between Single Setting and Group Setting designs. The topic of eye-tracking will be covered in detail in the next section, 2.4, including its both theoretical aspects and practical applications.

2.4. Eye Tracking

In researching cognitive and physiological differences that arise due to group effect on vigilance and social settings through a change detection task, eye tracking was employed as the primary mode of data collection in the experimental setting of the present study. In broadest terms, eye tracking can be defined as the measuring of eye positions and movements on a given stimulus (Holmqvist & Andersson, 2017).

Before moving on to the eye tracking systems, a short overview of the physiology of the human eye and eye movements will be presented in regards to visual perception. In order to *see* or process visual information, like any other lens, the human eye needs light. Light that is reflected from entities and various surroundings enter the eye through the pupil. This image is then projected upside-down to the retina, where it is transformed into electrical signals and sent to the visual cortex via the optic nerve to be processed (Holmqvist & Andersson, 2017).

The eye movements and direction of the gaze are decided by the orientation of the eye inside the head. This orientation is controlled by three pairs of muscles, which allow the eye to have both voluntary and involuntary three-dimensional movement (Holmqvist & Andersson, 2017). Some of the most commonly investigated gaze events are fixations, saccades and smooth pursuit. Fixations do not refer to a movement, but a state of eye events where the eye is relatively still for a certain period of time. The eye is not necessarily completely still during a fixation. For example, small movements such as microsaccades, tremors and drifts can be classified within a fixation as well (Rucci, McGraw, & Krauzlis, 2016). The rapid and jump-like movement from one fixation to another is called a saccade (Krauzlis, 2005). It is assumed that no visual information is processed during a saccade (Rensink et al., 2000). And finally, an eye movement that is mechanically and cognitively very different from saccades is smooth pursuit. Smooth pursuit is a feedback or stimuli driven movement of following a moving object (Holmqvist & Andersson, 2017; Krauzlis, 2005).

Eye events and movements have been studied in various fields of science. To measure and analyze eye events on a given stimulus the study and technologies of eye tracking has emerged. Even though the initial studies focusing on eye movements used quite different methods, video-based eye tracking devices are used commonly today (Holmqvist & Andersson, 2017). Most of current state-of-art eye trackers use a similar technology that uses *non-collimated* infrared and near-infrared light. Non-collimated light refers to a beam of light where rays within the beam are not parallel to each other (Edmund Optics). Moreover, infrared light is a type of electromagnetic radiation emitted from warm entities in the universe, with a wavelength longer than the red end of the visible spectrum and shorter than microwave and near infrared light refers to the relatively cooler and side of the infrared spectrum (Swinburne Centre for Astrophysics & Supercomputing).

When operated, the eye tracker device emits infrared light beams, as was mentioned earlier, that are reflected from the eye surface. These corneal reflections (CR) are recorded by a camera to be processed. By using the center of the pupil as a reference point, the vector between the pupil and CR is calculated to identify a gaze location for a given time. From this information a coordinate based or visualized representation of gaze and eye movements can be stored as the raw eye movement data (Hansen & Ji, 2010; Holmqvist & Andersson, 2017).

Various fields and domains of science has constituted research interests for eye tracking paradigms. Among the domains of cognitive science; attention, memory and workload of the mind have received interest and were investigated by researchers using eye tracking methodology (Holmqvist & Andersson, 2017). As an example of memory, more specifically short-term visual memory research using eye tracking, change blindness paradigm arises. Various studies regarding change blindness was presented in the previous section (2.3), however it is important to note that the phenomenon of change blindness is also explored within the eye tracking context (O'Regan et al., 2000).

In line with the present study, social interaction paradigms were also involved in eye tracking research. In the case of social interaction, the general idea is that attention can be dictated by social expectations and that this effect can be translated into eye events and movements. One example is that, a study has found that multiple participants in a group setting looked around same areas of research when they believed that they were all completing the same task, even without communication (Richardson et al., 2012). Moreover, another study has found that gaze was affected by cultural aspects and situations and social interactions as well (Crosby, Monin, & Richardson, 2008). That study has shown that a group of participants directed their attention towards one member of the group when that member made specifically offensive remarks towards a social group or community.

The present study also aims at observing effects of social interaction and being in a group on eye movements, however unlike the aforementioned eye tracking studies exploring social interactions, the expected effect of the present experimental research is on speed and alertness rather than mutual expectation of gaze locations or cultural aspects of social cognition. Moreover, in order to record and evaluate the eye movements of multiple participants at once, the Group Eye Tracking (GET) paradigm was employed in this research (Deniz, Fal, Bozkurt, & Acartürk, 2015). In order to investigate whether group size effect on vigilance can be observed in eye movements of humans, the present study has chosen to combine social interaction paradigms with change blindness as a group detection task.

CHAPTER 3

METHODOLOGY

3.1. Participants

Thirty participants (15 females) participated in a within-subjects study. All participants attended both the Single Setting and the Group Setting conditions of the experiment design, in one session. For each session of the experiment, three participants attended the experiment in a group. In the Single Setting, the participants completed the experiment individually, taking turns. In the Group Setting, all three of the participants in an experiment session completed the experiment together. Half of the participants completed the Single Setting first and the other half completed the Group Setting first for randomization of the order of presentation of the stimuli. All of the participants had normal or corrected-to-normal vision, with the exception of contact lenses that were not allowed during the experiment.

Participants were all Middle East Technical University (METU) undergraduate and graduate students and were enrolled via personal contacts, e-mail and social media. Participants attended the experiment for monetary compensation.

3.2. Stimuli

The stimuli consisted of a total of 99 images and three different sets of stimuli. All sets contained one reference image and 32 alternates of that reference image. These sets (viz. set A, set B and set C) did not differ in terms of their visual properties but in terms of visual look. In other words, all of them contained the necessary conditions to serve the purpose of the experiment, but they were not identical in how they look, in order to ensure variance within the stimuli.

3.2.1. Reference Images

All three of the stimulus sets contained one reference image that served as a default blueprint for that set and all other images within the set were alternate variations of the reference image. These reference images are named as <set name>_<default>. So, for example, a_default refers to the reference image of set A.

The reference image was 1024*768 pixels, which corresponded to full-screen resolution of the screens that were used in this experiment. In preparation of the reference image, the screen was divided into eight zones that are equal in size, as can be seen in the Figure 1.

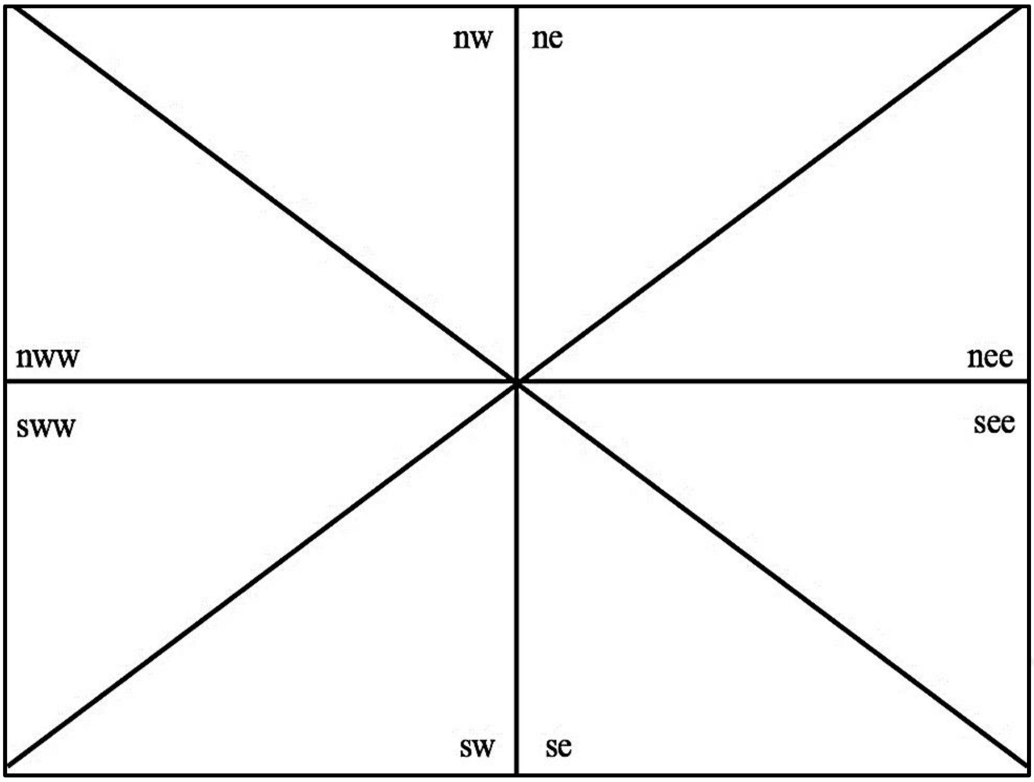

Figure 1. Eight zones of stimuli.

As can be seen in Figure 1, the areas were named as *ne, nw, nee, nww, se, sw, see and sww*. Then, the screen was once more separated into three parts as center, middle and edges, which can be seen in Figure 2. Neither of these divisions was, however, seen by the participants nor present on the participant display. They rather served as guides in preparation of the stimuli.

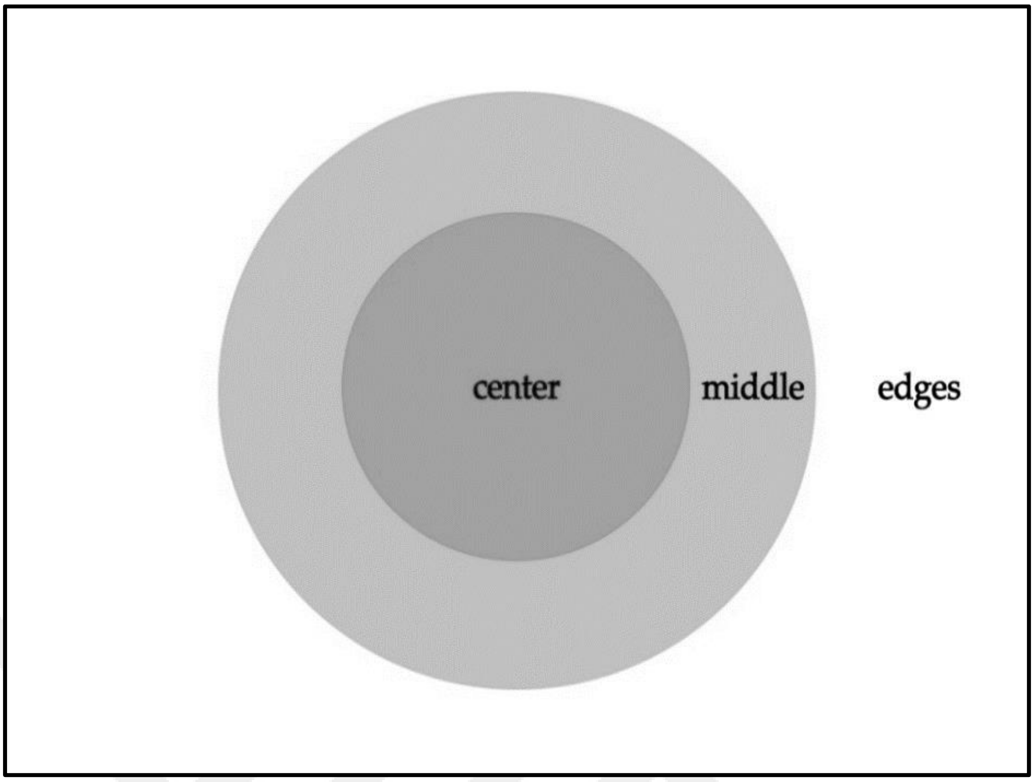

Figure 2. Center, middle and edges of an image.

The image was later filled with 18 types of circles of varying numbers. Six of these circles were black (color code: #000000), six of them were white (color code: #ffffff) and six of them were grey. The color code of the grey circles was #959595, rather than the conventional 18% grey (Brown, 2016), for better visibility. Moreover, six of these circles were large (radius = 70px), six of them were medium sized (radius = 50px) and six were small (radius = 35px). Some of the circles had a border of 3px width in one of the other two colors. The borders were used mainly to make white circles visible and to create aesthetic variance. All 18 types of circles that were used to produce the stimuli are given in Figure 3.

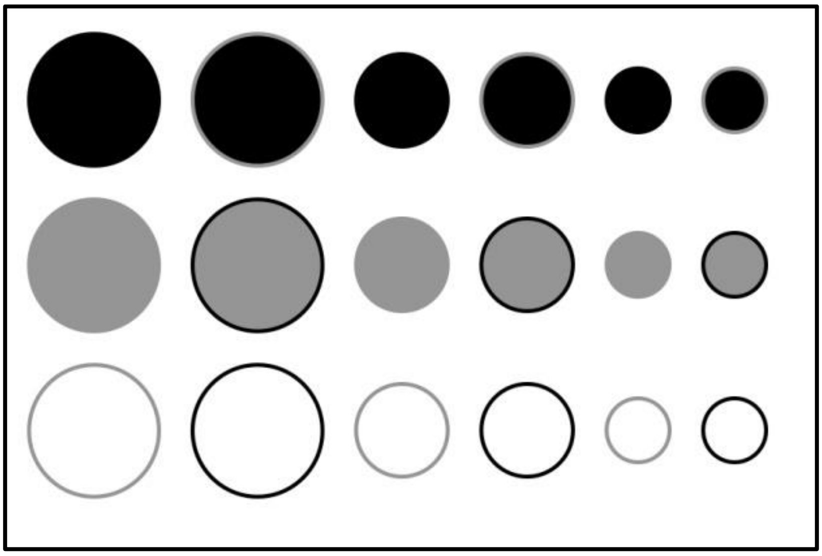

Figure 3. 18 types of circles used in stimuli.

The circles were placed in all 8 zones of the image (*ne, nw, nee, nww, se, sw, see, sww*) and all three parts in relation to distance to the center (center, middle, edges). While the circles in center and middle areas were placed randomly to create a crowded looking image, the circles around the edges were placed in a manner that would allow; 1) for all 8 zones to have an equal number of circles around the edges (four) and 2) for all zones to have two of each color (black, grey and white) and two of each size (large, medium and small). Whether or not a circle had border was not taken into account when distributing the circles throughout the image. The reference images of each set (set A, set B and set C) are given in Figure 4, Figure 5 and Figure 6 respectively.

In order to improve the stimuli and force a saccadic change blindness effect (explained in detail in 2.3, Change Blindness) *a red circle* was introduced to the participants. The red circle (color code = #FF0000) had a radius of 50 pixels and was printed on top of the reference images in each trial, on one of the eight possible zones shown in Figure 1. One of these zones was selected randomly for the red circle to appear in each trial with a predetermined coordinate set for all eight of them. The experimental flow entailed that a change was introduced the moment a participant or all participants looked at the red circle. This function allowed two things for the experiment design; triggering the change and forcing a saccade from the participant simultaneously with that change.

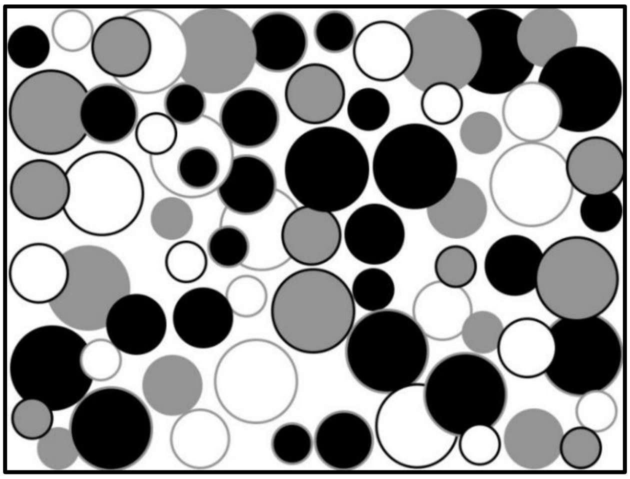

Figure 4. Main image of set A, not original size.

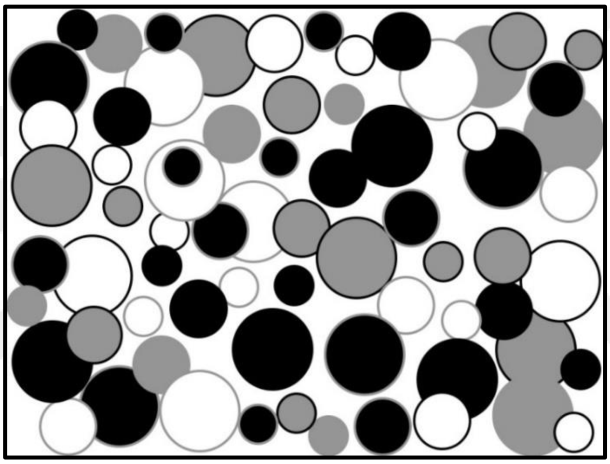

Figure 5. Main image of set B, not original size.

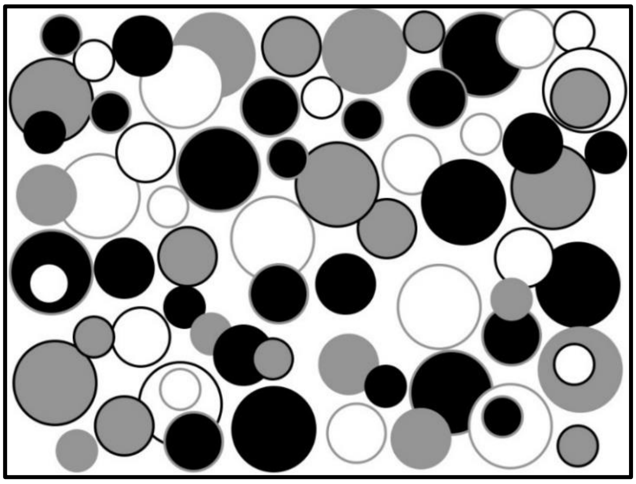

Figure 6. Main image of set C, not original size.

3.2.2. Alternate Images

From the reference images of all three sets, 32 alternate versions of that image were produced. These alternate images were identical to the main image, except for the color of a single circle. Accordingly, there were 33 images in a set, one reference image and 32 alternate versions of it that were all different from each other and different from the main image, as presented briefly in the previous section. The reason that there were 32 changed images is that four types of change were used in the experiment design and there were eight zones in the image (Figure 1), designated for changes. Therefore, there was an alternate image for 32 possible change type (4) and zone (8) combinations were created.

The aforementioned four types of change that were used were color-only changes. These four types of color changes were; black to grey, grey to black, white to grey and grey to white. For these changes, the same shades of the three colors as the circles in the reference image were used. For example, the change type of black to grey indicates that a circle that was black (color code: #000000) in the reference image was changed to grey (#959595). High-contrast color changes such as black to white or white to black were not used. In order to ensure that the changed circle and the red circle were not too close to each other, changes were made only in the 32 circles that were placed around the edges of the main image (edges can be seen in Figure 2). Moreover, to diminish the saliency of the change at least partially, only the medium and small sized circles were changed.

In order to ensure that the changed images were produced in a systematic manner, the following rules were followed for all images; 1) there must be an image for all 32 change type and zone combinations, 2) only one circle can change in every image, 3) only circles that are on the edges can change, 4) only the circles of medium and small sizes can change, 5) the circles can change only in color, not in size or location, 6) color change can be one of the following: black to grey, grey to black, white to grey, grey to white, 7) if the circle has a border, the border cannot be changed, 8) if the change is grey to white, then a grey and 3pt border will be added to the new white circle.

The changed images were named as `<set name>_<zone of change>_<initials of type of change>`. Therefore, the name `a_nw_gtb` suggests that the image is in set A and is a changed version of `a_default` and a grey circle in zone *nw* was changed to black in this image. As an example, names, change zones and change types of all the images in set A are given in Table 1.

Table 1. Names of changed images in set A.

	Change type			
Change Location	Black to grey	Grey to black	White to grey	Grey to white
nw	a_nw_btg	a_nw_gtb	a_nw_wtg	a_nw_gtw
ne	a_ne_btg	a_ne_gtb	a_ne_wtg	a_ne_gtw
nee	a_nee_btg	a_nee_gtb	a_nee_wtg	a_nee_gtw
see	a_see_btg	a_see_gtb	a_see_wtg	a_see_gtw
se	a_se_btg	a_se_gtb	a_se_wtg	a_se_gtw
sw	a_sw_btg	a_sw_gtb	a_sw_wtg	a_sw_gtw
sww	a_sww_btg	a_sww_gtb	a_sww_wtg	a_sww_gtw
nww	a_nww_btg	a_nww_gtb	a_nww_wtg	a_nww_gtw

The experiment design will be introduced and explained in detail in the following section.

3.3. Experiment Design

There were two within-subject experiment conditions: Single Setting and Group Setting. While the two were almost identical in experiment flow and general design, some technical changes were made for the purposes of the experiment design. These changes, which will be explained later on, were made in order to ensure that the task could be completed in groups of three or more people without introducing an element of competition between participants. Participants were not allowed to talk or discuss the task among themselves in neither of the experiment conditions. Therefore, the Group Setting was based on co-presence. Moreover, there was not a feedback mechanism in the experiment that informed the participants about their performance. In the Single Setting experiments, even though the participants completed the change blindness task alone, the researcher was present in the room, in order to successfully operate the experiment system.

3.3.1. Single Setting Design

The Single Setting design contained 40 trials with a three seconds (3000 milliseconds) waiting period in between the trials and took approximately 10 minutes to complete. Participants completed the test individually; all three people that were called in for one experiment session took turns in participating in the Single Setting experiment. Half of all participants completed this condition before moving on to the Group Setting.

All trials involved the same task of change detection, with varying stimuli and *change* condition. The change condition was a dependent variable for each trial that determined whether the trial contained a change or not. Each trial was randomly selected to be either a *Change* or a *No Change* trial. While this study mainly focused on Change trials, No Change trials were important in terms of creating randomness and variance in the stimuli, so that the participant was not always expecting a change. Moreover, the responses of participants to No Change trials were also used to determine the amount of false positive answers each participant had.

Within a trial, the participants first saw a randomly selected one of the three reference images (`a_default`, `b_default` or `c_default`). After three seconds (3000 ms), a red circle appeared on top of that reference image. The red circle could appear in one of the eight possible zones (*ne*, *nw*, *nee*, *nww*, *se*, *sw*, *see or sww*). While there was a predetermined set of coordinates for the red circle to appear in each of the 8 zones, exactly in which zone it appeared was randomly selected for each trial. The red circle in this experiment served two purposes. The first was to act as trigger function; it disappeared the moment participant looked at it and triggered the next image of the trial. And secondly it acted as a facilitator for saccadic change blindness (as described in 2.3, Change Blindness), since it forced eye movement the moment a change was introduced in the image.

If the trial was a Change trial, once the red circle disappeared from the screen, one of the 32 alternate images from the same set as the reference image would appear on the screen. The image shown to the participant as the alternate image had two aspects that were randomly selected: the location of the change (one of the eight zones) and type of the change (one of the four color-only change types). If the trial was a No Change trial, the red circle would function exactly the same but instead of the screen transitioning to an alternate image, the participant would see the first reference image they had seen in the beginning of the trial. In both Change and No Change trials, the transition between the image before and after the red circle was ensured to be seamless. The task presented to the participants was to search for a change and to press Spacebar on the keyboard with their right hand if they noticed one. Pressing Spacebar terminated the trial and the experiment proceeded to the next one. If there was no change or the participant failed to notice one, the trial would be terminated automatically after five seconds (5000 ms). In order to avoid any confusion, participants were explained that the red circle was not the change they were looking for but rather a diversion that would be used as a starting point for their eye movement. To clarify this flow further, Figure 7 shows the progression of one trial in a flowchart form. For clarity, Figure 7, demonstrates the alternate image with a red mark on the circle that the change was applied to in this particular example. That mark was not present on the participant display and is for this flowchart only.

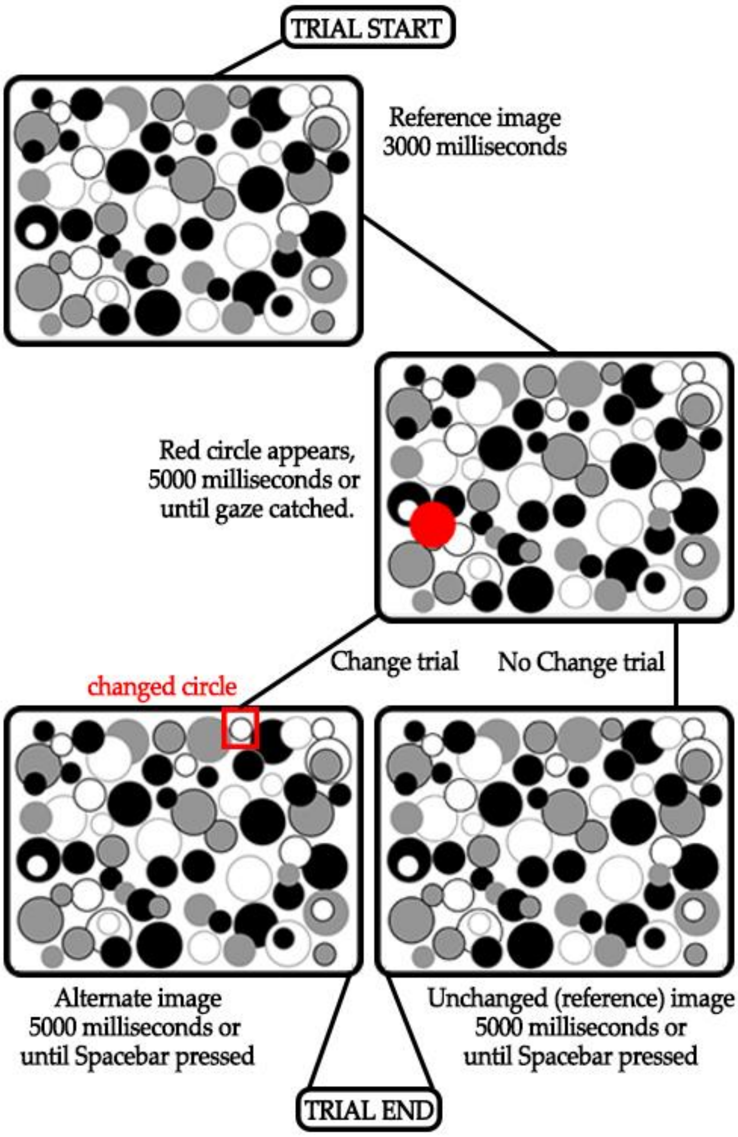

Figure 7. Flowchart showing trial progression.

3.3.2. Group Setting Design

The Group Setting experiment is similar to the Single Setting, except that all three participants that were called for the same session completed the experiment together in the Group Setting condition. The Group Setting also had 40 trials and took approximately 15 minutes to complete by a group of three people. Half of all participants completed Group Setting condition prior to Single Setting.

While the experiment flow, change condition, stimuli selection and the task were identical between the two settings, there were some differences between the two designs. One of the differences was how the red circle functioned. While it had exactly the same properties and trigger function; in the Group Setting the red circle required all three participants to look at it in order to trigger that function. While this affected the duration of each trial and the experiment slightly, it did not affect the eye movements during the search for the change. Secondly and similarly, one participant pressing Spacebar on their keyboard did not terminate the trial, all three needed to press it to progress further in the experiment. Their keypress data was recorded separately so that it is possible to evaluate the performance of each participant in the group separately.

These changes were implemented in order to enable the experiment to be performed on groups without changing the change detection task. Even though in this study, groups of three people participated in the Group Setting, the coding and infrastructure of the experiment allowed for more. Moreover, the changes in the red circle and Spacebar functions allowed the experiment to be performed on groups without adding an element of competition to the task; how fast the participants individually were, did not affect the flow of the experiment.

3.4. Eye Tracking Equipment

For data collection of eye movements in the present study, the Group Eye Tracking (GET) infrastructure in Informatics Institute, METU was used. The GET infrastructure was developed in 2016 by Ozan Deniz, Mehmetcan Fal and Cengiz Acartürk (Deniz, 2016; Deniz et al., 2015) and consisted of the client and the server. Within this infrastructure, all client PCs were connected to an eye tracker. The server received and listened to data sent from the client, including the eye movement raw data, and distributed data to the client PCs. Even though the infrastructure allowed for more, one client PC for Single Setting and three for Group Setting designs were used in this experiment. The GET software enabled the same system to run both Single and Group Setting experiments as well as providing a graphical user interface to customize the experiment parameters[1].

The eye trackers that were used to record eye movement data during the experiments were Eye Tribe eye trackers. The raw eye movement data in this study was obtained from the Eye Tribe API and was collected at a sampling rate of 30 Hz and after a 9-point calibration. The average accuracy of Eye Tribe eye trackers is 0.5 degrees, and the average spatial resolution is 0.1 degrees.

The system lag was measured for both Single and Group Setting experiments so that the delay between data leaving the client and being received by the server does not interfere with the time and speed analysis conducted on the raw eye movement data. The results of these measurements show that the system lag is approximately 10 milliseconds for Single Setting experiment and approximately 17 milliseconds for Group Setting experiments run with three client PCs.

3.5. Procedure and Data Preparation

Experimental part of the present study was conducted in a lab in the Informatics Institute of METU. The GET system was located in the lab, with all client PCs and the server. The screens of the client PCs were placed next to each other, each with a chin rest to stabilize the head. The screens were divided by a panel in between them. In Single Setting design, participants could use any one of the three PCs with their chin and foreheads placed on the chin rest. In Group Setting design

[1] The experiment design was adapted to the GET platform by Maani Tajaddini and Mine Özkul, who developed the latest version of the GET software.

all three participants were seated next to each other, with their chins and foreheads placed on the chin rest. The panels did not block a participant's view of the other two participants, but rather their view of the other two screens. The participants were instructed twice about the task by the experimenter, once before they started the Single Setting condition and once before Group Setting condition. They were not allowed to talk or discuss the task during the experiment. The layout of the lab and PC settings can be seen in Figure 8.

Figure 8. Photo of the lab used for conducting the experiments in the present study.

After the experiments in this thesis, two sets of data were produced. The first set involved keypress data from each experiment (both the Single and Group Settings) and presented which trials the participants pressed Spacebar on their keyboard. The second set was the eye tracker raw data set for all of the experiments in both conditions, obtained from the Eye Tribe API.

From the keypress data, it was possible to obtain accuracy rates separately for each participant where the conditions of; 1) trial is a No Change trial and the participant did not press Spacebar, 2) the trial is a Change trial and participant pressed Spacebar are both considered *correct answers* and all other conditions were considered *incorrect*. If the trial was a No Change trial and the participant did press the Spacebar, that trial was considered a False Positive. The results and analysis of accuracy data are presented in the next Chapter.

Secondly, the raw eye movement data was cleansed and specific cases of research interest were isolated from this data. Within the framework of the present study, only Change trials were taken into account for the eye movement analysis. Therefore, raw data of these trials were separated. Within each trial, only the eye movements between red circle appearing and participant noticing the change were relevant. These periods of eye tracking data were then isolated as well and the rest were not used for the present study. In order to determine whether or not the participant detected a change, eye movement data of a trial was always double checked with the keypress data of that specific trial and the participant's general accuracy performance was also taken into account to this end. Moreover, the eye movement data was investigated in various terms such as whether there were any consecutive data points on coordinates of the change; if so, how many and for how long; the amount of data points on the coordinates of the red circle; and whether the eye movement was directed from the red circle towards the change. After the data cleansing process, trials that were deemed suitable were included in the time and speed analysis of the eye movements, the results of which are also presented in Chapter 4.

CHAPTER 4

RESULTS

4.1. Accuracy

The participants in the present study were instructed to press the Spacebar on their keyboard if they noticed a change in the stimulus. Accordingly, their keypress data was used for the evaluation of accuracy and performance. Their accuracy in an experiment was calculated in two ways. First, a participants' accuracy in a total of 40 trials was calculated, and secondly their accuracy in only Change trials were taken into account. The false positive answers ware also taken into account for this part of the analysis, as presented below.

4.1.1. Total Accuracy

Total accuracy corresponds to the ratio of correct answers to incorrect answers in a total of 40 trials within one condition of the experiment. Among a total of 60 experiment sessions including both the Single Setting and the Group Setting, 55 were usable for this analysis. The remaining experiments were excluded due to participants misunderstanding the given task (e.g., consecutive pressing of the spacebar key). In these 55 experiment sessions participants had a mean accuracy score of 83.86 over 100 (SD=16.27).

Total accuracy scores of participants in the Single Setting and the Group Setting experiments were compared by means of an independent samples t-test. The mean accuracy score of participants in the Single Setting design was 85.80 % (SD=15.90) and 81.85 % (SD=16.80) for the Group Setting. The t-test results demonstrated that there was not a significant difference between the Single Setting and the Group Setting mean accuracies ($t(53)$=.899, p>.05), as shown in Table 2. Accordingly, Cohen's effect size value (d = 0.22) suggests a small size of effect.

Table 2. t-test results for total accuracy between Single Setting and Group Setting.

Mean		t-test		
Single	Group	*t*	*df*	Sig.
85.80 (15.89)	81.85 (16.79)	.899	53	.373

Note: Standard Deviations appear in parentheses below means.

Even though in the independent samples t-test presented above, since data was collected from the same participants twice in two different experiment conditions, dependent t-test is also suitable for the within-subjects experiment in the present study. The results of the dependent t-test comparing the Single and Group Settings in terms of accuracy in a total of 40 trials is given below in Table 3. The results show that there is not a significant difference between the Single and Group Setting experiments in terms of total accuracy ($t(26)=1.200$, $p>.05$).

Table 3. Dependent t-test for total accuracy between Single Setting and Group Setting.

Mean		t-test		
Single	Group	*t*	*df*	Sig.
85.80 (16.14)	81.85 (16.70)	1.200	26	.241

Note: Standard Deviations appear in parentheses below means.

Finally, another independent samples t-test was conducted to compare the means of female and male participants in terms of total accuracy values. Male participants had a mean accuracy of 84.83 % (SD=17.46) while females had a mean accuracy of 82.70 % (SD=14.98). The results suggest that there was not a significant difference between male and female participants in terms of their accuracy in a total of 40 trials within one condition of an experiment session ($t(30)=.481$, $p>.05$). These results are shown in Table 4. Further, Cohen's effect size value suggests that the size of effect was very small with $d = 0.13$.

Table 4. t-test results for total accuracy between male and female participants.

Mean		t-test		
Male	Female	*t*	*df*	Sig.
84.83 (17.46)	82.70 (14.98)	.481	30	.633

Note: Standard Deviations appear in parentheses below means.

Comparing gender differences was not one of the purposes of the present study and gender was not a controlled factor during the experimental research involved in the present study. In order to further clarify this individual factor a 2x2 mixed ANOVA was conducted in order to explore the interaction between group effect and gender in terms of total accuracy. The results of the mixed ANOVA are given in Table 5. According to the results, there as not a significant interaction between experiment condition and gender on total accuracy ($F(1)=.293$, $p>.05$)

Table 5. 2x2 Mixed ANOVA results for gender and experiment condition, comparing total accuracy.

Mean				Condition*Gender ANOVA		
Male	Female	Single	Group	Sum of Squares	F	Sig.
84.83 (17.46)	82.70 (14.98)	85.80 (15.89)	81.85 (16.79)	45.317	.293	.594

Note: Standard Deviations appear in parentheses below means.

4.1.2. Accuracy in Change Trials

As was mentioned in Section 3.3, each trial in an experiment session was randomly selected to be either a Change or a No Change trial. Change trials contained a changed circle, differently from the reference images, that the participants attempted to detect. In this analysis, accuracy scores in only the Change trials were measured. These scores were calculated as the ratio of correct answers to incorrect answers given to the Change trials within one condition of an experiment session. The number of Change trials in an experiment could vary since whether a trial is Change or No Change was always selected randomly. In all 55 experiment sessions, independently from the setting of experiments, the mean accuracy score of the participants was 83.92 % (SD=20.94).

When the mean accuracy scores in Change trials were compared between participants in the Single Setting and the Group Setting conditions, the results showed that there was not a significant difference between the two settings in terms of accuracy in Change trials ($t(53)=1.387$, $p>.05$). The statistical details of this t-test are given in Table 6. Moreover, it appears that the effect size was small with Cohen's *d* being 0.37.

Table 6. t-test results for accuracy in Change trials between Single and Group Settings.

Mean		t-test		
Single	Group	*t*	*df*	Sig.
87.74 (17.14)	79.97 (23.96)	1.387	53	.171

Note: Standard Deviations appear in parentheses below means.

Similarly to total accuracy results, since data was collected from the same participants twice, once for the Single Setting and once for the Group Setting, dependent t-test is also suitable for the purposes of the present study. The results of the dependent t-test comparing the Single Setting and the Group Setting in terms of accuracy in Change trials is given below in Table 7. The results of the dependent t-test demonstrate that accuracy in only Change trials was not significantly different ($p>.05$) between the Single and the Group Setting of the experiment reported in the present study with $t(26)=1.741$.

Table 7. Dependent t-test results for accuracy in Change trials between Single and Group Settings.

Mean		t-test		
Single	Group	*t*	*df*	Sig.
87.74 (17.47)	79.97 (23.96)	1.741	26	.093

Note: Standard Deviations appear in parentheses below means.

The Change trial accuracy scores of female and male participants were also compared. It is seen that female participants had a lower mean of accuracy (Mean=75.78%, SD=26.77) when compared to male participants who had a mean of 90.72 % (SD=10.90). However, the Levene's test was also significant for these results at $p < .01$ level ($F(30)=20.683$), suggesting that there was a considerable amount of variance in the data. Therefore, a non-parametric Mann-Whitney U test was conducted to compare the accuracy scores of female and male participants in Change trials, results of which are given in Table 8. The results show that there is a difference between the mean accuracy scores of female and male participants in Change trials ($p<.05$). Further, Cohen's effect size value ($d = 0.73$) shows that the effect size was rather large.

Table 8. Levene's and Mann-Whitney results for accuracy in Change trials, between females and males.

Mean		Levene's Test		Mann-Whitney			
Male	Female	F	Sig.	Mann Whitney U	Wilcoxon W	Z	Sig.
90.72 (10.90)	75.78 (26.77)	20.683	.000**	243.0	568.0	-2.255	.024*

Note: * < .05, ** < .01, Standard Deviations appear in parentheses below means.

In order to control if the interaction of experiment condition (Single Setting vs. Group Setting) and gender has a significant effect on accuracy in change trials, a 2x2 mixed ANOVA was conducted to compare these variables. The results of the ANOVA show that this interaction did not affect accuracy in Change trials significantly ($F(1)=1.087$,$p>.05$) These results are shown in Table 9.

Table 9. 2x2 Mixed ANOVA results for gender and experiment condition, comparing accuracy in Change trials.

Mean				Condition*Gender ANOVA		
Male	Female	Single	Group	Sum of Squares	F	Sig.
90.72 (10.90)	75.78 (26.77)	87.74 (17.14)	79.97 (23.96)	175,757	1.087	.309

Note: Standard Deviations appear in parentheses below means.

4.1.3. Number of False Positive Answers

False positive answers, where a participant pressed the Spacebar even though the trial was a No Change trial were also taken into account in this analysis. All the participants, regardless of the gender or the experiment setting, had a mean number of 3.56 false positive answers out of 40 (SD=5.6).

When the number of false positive answers was reviewed in terms of the experiment setting, it is seen that the numbers in the Single Setting and the Group setting designs were not significantly different ($t(53)$=-.371 , p>.05).

Table 10. t-tests for number of false positive answers between Single and Group settings, and male and female participants.

		t-test		
Condition	Mean	t	df	Sig.
Single	3.28 (5.44)	-.371	53	.712
Group	3.85 (5.86)			
Male	4.33 (6.31)	1.118	53	.269
Female	2.64 (4.58)			

Note: Standard Deviations appear in parentheses below means.

Similarly, amount of false positive answers coming from the female and the male participants were not significantly different either, with $t(53)$=1.118 (p>.05). Both these results are presented in Table 10.

4.2. Eye Movement Measures

For the eye-movement analysis, among 30 participants in each experimental setting; data from 27 participants (12 females) were included into the analyses for the Single Setting design. For the Group Setting condition, data from 23 (9 females) participants were used in the analyses. The remaining data were excluded due to calibration problems at the beginning of the experiment session or the loss of calibration during the experiment session. As was explained in subsection 3.5 in the Methodology chapter, Change trials were isolated from the eye tracking data. Later on, the isolated section was filtered to determine raw data points of eye tracking coordinates that corresponded to the coordinates of the Areas of Interest (AOI), namely the red circle and the changed circle. Time that passed between participant looking at the red circle and the changed circle was taken into account by involving that section of eye movement data in the analysis as well.

In accordance with the hypotheses of this study, two factors became significant; duration and speed of eye movements. From the eye tracking data, it was possible to determine two different measures of duration; 1) time spent between the red circle's onset (i.e., its first appearance on the screen) and the participant's first noticing the change and 2) the time spent between the participant's gaze leaving the red circle and the participant's first noticing the change. For brevity reasons, these variables will be referred to as "duration from the red circle onset" and "duration from the red circle end" from here on. These duration measurements are shown in Figure 9 in the form of a flowchart. In this flowchart, time intervals for both measurements are presented in an exemplified Change trial. The gaze of the participant is represented by a green circle, and the change is marked for demonstration purposes.

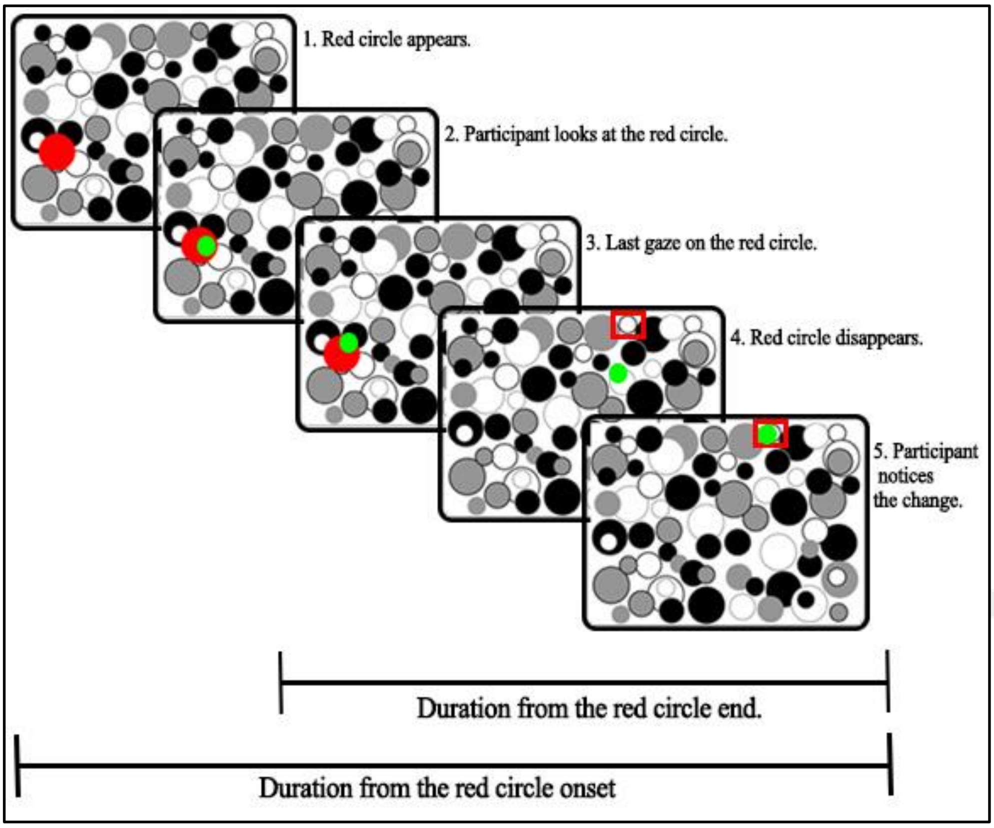

Figure 9. Duration measurements in the form of a flowchart.

As for speed, the eye movement (saccade) speed of the participant was calculated in pixels/milliseconds (px/ms) and this data was obtained by dividing duration from the red circle end to the distance (in pixels) between the red circle and the changed circle for each trial.

4.2.1. Duration Analysis

First of all, the duration from the red circle onset was taken into account for the Change trials. All the participants in both settings had a mean time from the red circle onset value of 683.669 ms (SD=855.035). The mean duration from the red circle onset values of the Single Setting and the Group Setting conditions were compared. As Levene's test was significant ($F(320)=117.382$, $p<.01$), some variance was assumed in the data. For this reason, instead of ANOVA, a non-parametric Mann- Whitney test was conducted and the results given in Table 11. The results show that durations from the red circle onset was were significantly longer in the Group Setting of the experiment (*p*<.01). Cohen's effect size value for this analysis (*d* = 0.54) suggests that the effect size was moderate.

Table 11. Levene's and Mann-Whitney results for duration from the red circle onset, between the Single and Group Settings.

Mean		Levene's Test		Mann-Whitney			
Single	Group	F	Sig.	Mann Whitney U	Wilcoxon W	Z	Sig.
471.437 (363.442)	943.707 (1160.483)	117.382	.000**	31732.5	89362.5	-6.943	.000*

Note: ** < .01, Standard Deviations appear in parentheses below means.

Secondly, duration from the red circle end was analyzed and the mean time of all the participants was 251.838 ms (SD=481.449). The difference between Single Setting and Group Setting was compared in terms of duration from red circle end However, since Levene's Test was significant at *p*<.01 level, homogeneity of variance could not be assumed for the data (*F*(401)=41.723) and the non-parametric Mann-Whitney U test was conducted. The results show that durations from the red circle end was significantly longer in the Group Setting conditions (see Table 12). In contrast, the Cohen's effect size value (*d* = 0.39) suggests that the effect size of experiment condition to duration from the red circle was relatively small.

Table 12. Levene's and Mann-Whitney results for duration from the red circle end, between the Single and Group Settings.

Mean		Levene's Test		Mann Whitney			
Single	Group	F	Sig.	Mann Whitney U	Wilcoxon W	Z	Sig.
165.765 (323.770)	356.883 (607.759)	41.723	.000**	34873.0	92503.0	-5.557	.000**

Note: ** < .01, Standard Deviations appear in parentheses below means.

4.2.2. Speed Analysis

In the duration analyses significant variance values were observed in the data. These variances could be due to individual differences between the participants as well as the design of the stimulus. Since the red circle was accepted as a starting point for the eye movement, one main difference the visual elements of the stimulus could have created was the distance between the red circle and the changed circle. It is important to note that the locations of both these circles were selected randomly for each trial, with varying distances from each other. Therefore, in order to eliminate this effect, the speed of eye movement was calculated for each trial that was involved in the analysis. For this calculation, the duration from red circle end was a better fit for the time variable, since there is a high probability that a significant amount of the duration from red circle onset was spent on the red circle itself. Accordingly, speed was calculated in pixels/milliseconds, by dividing the distance between the red circle and the changed circle by the duration of the eye movement.

The results of the t-test and ANOVA comparing speed means between the Single and the Group Setting conditions are given in Table 13 and the boxplot for these results is shown in Figure 10. The participants in the Single Setting had a mean speed of 5.3 px/ms (SD=3.4), while the participants in the Group Setting had a mean speed of 3.98 px/ms (SD=3.65). ANOVA results comparing these two values suggest that the participants in the Single Setting were significantly faster when compared to participants in the Group Setting ($F(614)=21.493$, $p<.01$). Similarly, the independent samples t-test also show a significant difference between two experimental settings ($t(614)=4.636$, $p<.01$). However, the effect size is relatively small with Cohen's *d* being 0.37.

Table 13. Independent Samples t-test and ANOVA for speed between Single and Group Settings.

Mean		Levene's Test		t-test			ANOVA	
Single	Group	F	Sig.	*t*	*df*	Sig.	F	Sig.
5.30 (3.40)	3.98 (3.65)	0.46	.831	4.636	614	.000**	21.493	.000**

Note: ** < .01, Standard Deviations appear in parentheses below means.

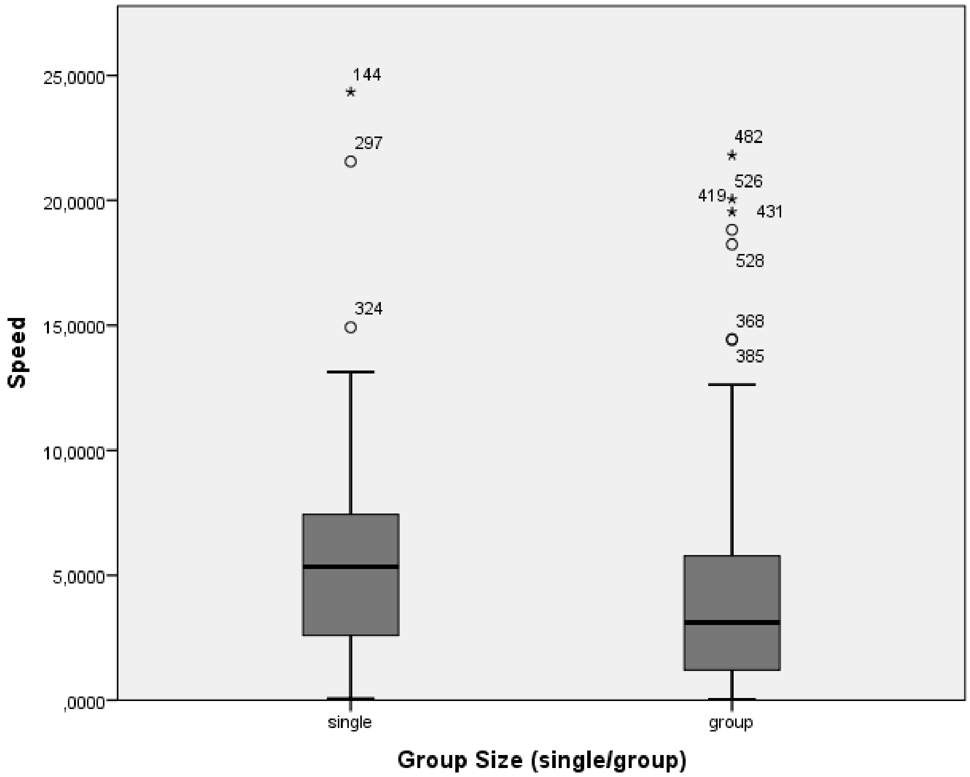

Figure 10. Boxplot showing eye movement speed in the Single and Group Settings.

In summary, for the eye movement analysis, a bar graph showing time from red circle onset and time from red circle end in regards to Single and Group Settings is given in Figure 11 and another bar graph showing speed (px/ms) analysis in comparison to two experiment settings is given in Figure 12.

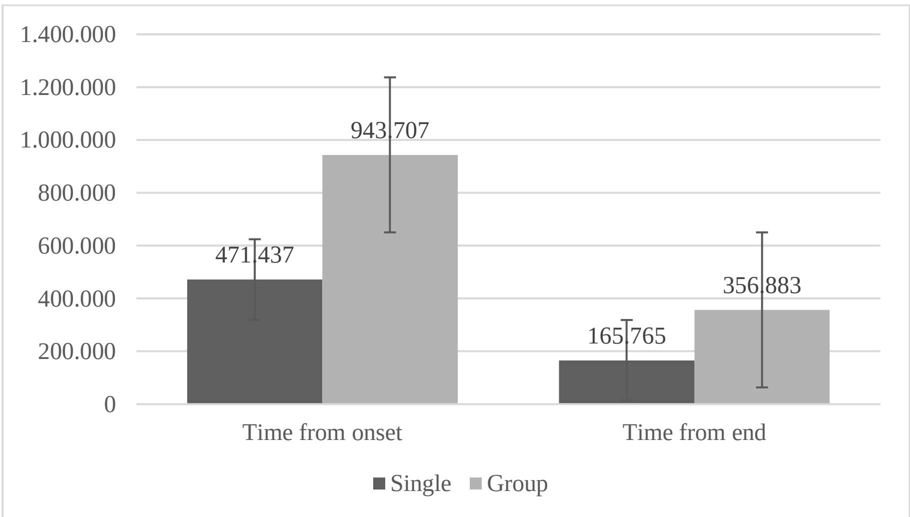

Figure 11. Bar graph showing time comparisons of eye movements between Single and Group Settings.

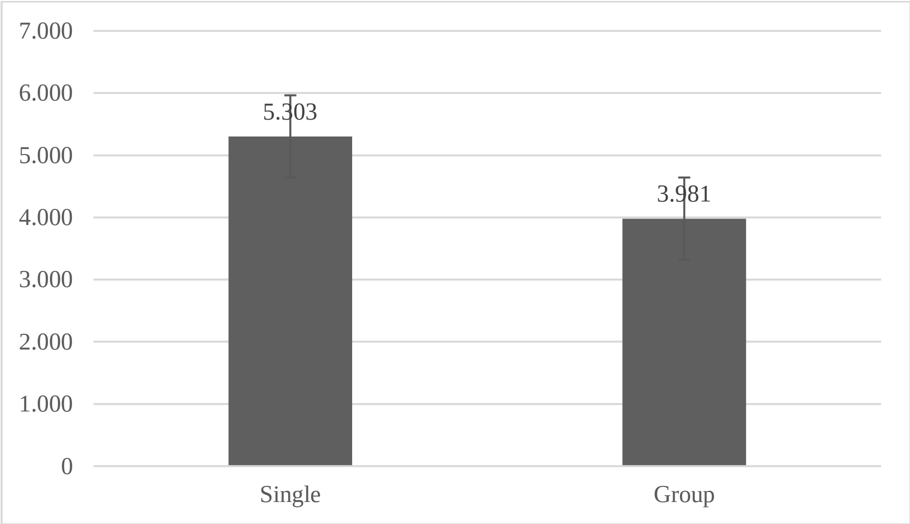

Figure 12. Bar graph showing speed (px/ms) comparisons between Single and Group Settings.

4.3. Change Type and Changed Circle Size

In order to experimentally control the effect of visual factors in the stimuli, the eye movement speed (in px/ms) were compared against two visual factors; the type of the change (i.e. grey to black, black to grey, grey to white and white to grey changes) and the size of the changed circle (small or medium; respectively 35 or 50 px in radius). The various types of circles involved in the stimuli are shown in Figure 13. This Figure is repeated from "Figure 3. 18 types of circles used in stimuli.", in Section 3.2.1.

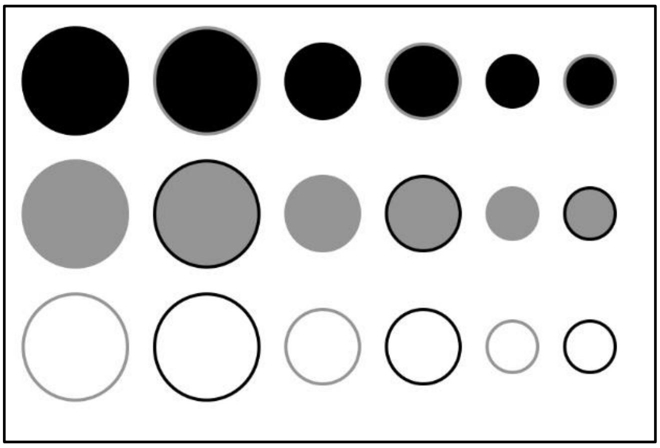

Figure 13. Types of circles used in the stimuli (repeated figure).

For both change types and sizes of the changed circle, an ANOVA test was run comparing them in speed in px/ms. These results are shown in Table 14. The results show that neither change type (*F*(615)=2.110), nor the size of the changed circle ($F(615)=.279$) were significant factors in determining eye movement speed of the participants, with $p>.05$.

Table 14. ANOVA results for speed(px/ms), between change types and size of the changed circle.

Visual Element	ANOVA	
	F	Sig.
Change type	2.110	.098
Size of the changed circle	.279	.598

4.4. Overall Summary of the Results

In summary, the results have shown that total accuracy rates of Single and Group Setting participants were not significantly different from each other. Similarly, neither the accuracy in Change trials nor the amount of false positive answers were different between the two conditions of experiment design. In order to reduce the effect of individual factors, accuracy rates and false positive answers were compared in terms of the gender of the participant. Among these comparisons, only accuracy in Change trials was significantly different between male and female participants; while total accuracy rate and amount of false positive answers were not. Moreover, the interaction of gender and experiment conditions (Single vs. Group) was controlled in terms of its effect on total accuracy and accuracy on Change trials, however neither these tests were significant.

In eye movement analyses, two factors were emphasized; duration and speed of the eye movement. For duration, both duration between the red circle onset and the participant first noticing the change (duration from the red circle onset), and the duration between the last gaze on the red circle and first gaze on the changed circle (duration from the red circle end) were considered. Both these measurements were shown to be significantly different between the Single and the Group Settings of the experiment. As for speed, speed was calculated in px/ms, by dividing the distance between the red circle and the changed circle by the duration from the red circle end. Speed of eye movements was also shown to be significantly different between the two conditions of the experiment.

Finally, in order to eliminate any visual element that may affect speed of eye movements, the four change types and the size of the changed circle were compared to eye movement speed. It was shown that neither of these elements were significant factors in terms of eye movement speed.

CHAPTER 5

CONCLUSION AND DISCUSSION

Within the research domain of social cognition in groups, vigilance was the topic the present study has focused mostly on. One of the outcomes of vigilance research is the group size effect (Lima, 1995), a social effect that the present study tried to replicate in human subjects. To this end, a change detection task was employed as the experiment design and the visual perception phenomenon of change blindness (Simons & Levin, 1997) was explored.

This chapter will begin by discussing and evaluating various findings of the experimental part of the present research. Results of accuracy rates, compared between the Single and the Group Setting designs will be evaluated. Later on, the main focal point of the present study, results of time and speed analysis will be discussed along with suggesting a theoretical explanation to the findings. After presenting the limitations and shortcomings of this study, possible future directions for the present line of research will be discussed.

5.1. Discussion of Accuracy Results

The results of accuracy rate analysis comparing the Single and the Group Setting designs was presented in 4.1. Accuracy in the present analysis was calculated as the rate of correct answers to all answers and both accuracy in the entire experiments and accuracy in only change trials were given. The group size effect was considered as a decline in vigilance in relation to the increase in group size. Since the vigilance itself may not be easy to directly observe or measure (Beauchamp, 2015), the present study has chosen a change detection task in order to evaluate the performance of the participants. In this context, one of the hypotheses of the present study was that the decrease in vigilance would be visible as a decrease in general performance in the form of accuracy. This effect, however was not observed in the data and the hypothesis was not supported in the present study.

In order to take into account the individual performance differences, gender was also taken into account in this analysis, since it is a widely varying factor in various vigilance studies (Whiteside et al., 2016). Neither total accuracy nor the amount of false positive answers was different between males and females. While the accuracy ratings in only change trials were significantly different between males and females, a large amount of variance was observed in the data (F=20.683, p<.01). Considering the limited number of participants, this effect may have occurred due to other individual factors rather than gender itself. In addition, the mixed ANOVA tests that were conducted in order to observe the effect of experiment condition and gender on both scores of accuracy measurements showed that the interaction of these two variables did not have a significant effect on neither total accuracy nor accuracy in Change trials. It is a limitation of the present study that gender was not sufficiently controlled during the experimental research. Even though close numbers of participants from each gender attended the experiment, the combination of gender and grouping of the participants was not taken into account.

The results of the accuracy analyze demonstrate that the accuracy ratings of the participants were not significantly different in groups compared to single individuals. This was true for both total accuracy and accuracy in only change trials. Similarly, the number of false positive answers was not significantly different in the two conditions of the experiment either. Accordingly, the results regarding the performance of participants were different from what was expected. There may be various reasons as to why the experiment did not produce the expected results. First of all, on a very practical aspect, the participants were instructed to press Spacebar slowly and as silently as possible when they noticed the change. However, in some trials, it is possible that the participants were able to hear a key being pressed and automatically press it themselves without actually noticing a change. Moreover, it is also possible that the task was too simple for the participants and in accordance, the curve of accuracy was too high to observe any significant difference in performance.

While it can be assumed that within the given framework of experiment design, the performance in change detection does differ between singe individuals and groups; this effect was not sufficient to entirely rule out group size effect and a decline in vigilance in groups. The results of the eye movement data are quite indicative in that sense and supporting of the primary hypotheses of the present study.

5.2. Discussion of Eye Movement Results

Another hypothesis of the present study was that in a change blindness experiment, the eye movements of the participants would be slower in detecting the change when they completed the task in a group. This idea was highly related to group size effect; an effect observed in groups as a negative relation between vigilance and the number of members in a group (Beauchamp, 2008). Since vigilance is generally defined as a state of alertness towards surroundings and the willingness to detect and respond to the given stimulus (Warm et al., 2008), a change detection task was selected as a means to investigate group size effect in humans. As the present study expected that eye movements of the participants would be slower in the Group Setting, eye tracking was used primarily for data collection. Reports of analysis on eye movement data were presented in section 4.2.

In analyzing eye movement data from the experiments, two factors were focused on. These factors were the duration between red circle and noticing the change and speed of this eye movement in pixels/milliseconds. In the case of duration analysis of the eye movement data, two different measurements of time with different starting points were considered; duration from the red circle onset and duration from the red circle end These measurements corresponded to time spent between the red circle appearing and first gaze on changed circle and time spent between last gaze on red circle and first gaze on changed circle respectively. In both of these measurements, it was observed that the Single and the Group Setting conditions were significantly different from each other and it took the participants significantly longer time to notice the change when they were in the Group Setting. Secondly, in speed (px/ms) measurements, it was observed that participants were significantly slower at detecting a change in the Group Setting condition than in the Single Setting at $p<.01$ level.

Moreover, in order to eliminate factors that could have occurred in relation to the visual elements of the stimuli, the four change types (grey to black, black to grey, grey to white and white to grey) as well as the size of changed circle (35px or 50px in radius) were compared in terms of eye movements. The results of the analysis showed that speed of eye movements was not significantly related to either of these elements. Therefore, it can be suggested that the effect observed in speed is not a result of visual elements in the stimuli.

The present study has demonstrated that eye movements of participants were rather significantly slower when they were in the Group Setting. Therefore, it can be suggested this hypothesis of the present thesis and expectations regarding the experimental research were shown to be supported within this framework and it is possible to consider these results as indicative of group size effect in humans.

5.3. Limitations and Future Work

In the present study, the experiments were conducted with 30 participants and some variance was observed in both accuracy and eye movement measurements. In order to better eliminate individual differences in performance and other factors, a larger pool of participants would be beneficial. In the eye movement analyses, only time and speed were focused on as the determining factors, but a more detailed eye tracking analysis could have shed more light on the topic. Moreover, even though a difference in accuracy was observed between female and male participants, the purpose of the present study was not to investigate differences between genders. Therefore, this factor was not sufficiently controlled during the experimental research involved in the present thesis. A more controlled study regarding gender factors could prove beneficial in clarifying the reasons and mechanisms behind the difference in accuracy. Additionally, investigating gaze patterns in No Change trials could yield valuable results, even though not entirely related to the hypotheses of the present study.

While it is commonplace of group behavior experiments to explore relatively more complex task than the one presented in the present study, we have chosen to limit the interaction between participants in order to at least partially control the group effect. Even though an evolutionary explanation (group effect and vigilance) was deemed a better fit in the mechanisms explored in the present study, other mechanisms and processes could possibly be the underlying effect in this phenomenon. For example, the emotional states of the participants were not checked or controlled during the present research. Time of the day, emotional state, sleep deprivation and other factors could affect vigilance and how the participants adjust to the group effect.

One of the hypotheses of the present study was that the group size effect would be observable at a physiological level in a change blindness experiment. To this end, we have considered slower eye movements as a possible outcome of a decreased vigilance. It is possible to claim that this hypothesis was supported by the experimental research reported in the present thesis, since the results of the experimental research indicate that eye movements are significantly slower when the people are in social settings. Secondly, it was hypothesized that a similar effect would be seen in the performance of the participants as well in that the accuracy ratings of participants would be lower in Group Setting. This hypothesis could not be supported by the data that was acquired in the experiments and some reasons for it was discussed in section 5.1.

Finally, the main hypothesis of the present study was that the group size effect would be observable in a change blindness experiment. While a theoretical discussion can be held regarding whether change detection tasks are sufficient to observe and measure declines in vigilance, the results are quite promising in this context. It has been suggested before that the eye movements and gaze in general is an important part of the human information extraction methods, communication and social interaction (Emery, 2000). Since gaze is a primary mechanism of detection (Beauchamp, 2015), slower eye movements can indicate a drop in alertness. Therefore, it is our belief that the lower speed of eye movements that was observed in the Group Setting condition of the experiment can be attributed to a decrease in vigilance and the group size effect.

While vigilance is a widely investigated topic in animals, human studies in this area are rather scarce. Similarly, there were various group size effect studies regarding animals, but very little with humans. To our knowledge, the present study is the first study to combine vigilance and change blindness in an experimental research and the first study to use eye tracking in a vigilance study. Therefore, it is our belief that this study contributes to the literature of vigilance and group size effect, both by implementing a novel idea and supporting the main hypothesis in a systematic experimental paradigm.

In conclusion, this topic could prove to be an important step in further developing the social cognition research domain and understanding the evolutionary basis behind social structures that humans have built so far. Therefore, in the future, it is the hope of this researcher that more research about group size effect in humans will be held with larger and more diverse populations.

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