

EXPLORING HAND MOVEMENT DYNAMICS DURING THE SIMON TASK: A  
MOUSE TRACKING STUDY

A THESIS SUBMITTED TO  
THE GRADUATE SCHOOL OF INFORMATICS OF  
THE MIDDLE EAST TECHNICAL UNIVERSITY  
BY

HATİCE BUKET İKİZOĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE  
IN  
THE DEPARTMENT OF COGNITIVE SCIENCE

DECEMBER 2019



Approval of the thesis:

**EXPLORING HAND MOVEMENT DYNAMICS DURING THE SIMON TASK: A MOUSE TRACKING STUDY**

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## **ABSTRACT**

### **EXPLORING HAND MOVEMENT DYNAMICS DURING THE SIMON TASK: A MOUSE TRACKING STUDY**

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December 2019, 60 pages

Understanding how the cognitive system processes information in real-time is one of the key concerns for researchers in experimental psychology and cognitive science. Several measures and software tools have been proposed to explore different aspects of cognitive processing phenomena. One of these methods, mouse-tracking, allows researchers to collect data about the dynamic unfolding of motor responses by recording the participants' mouse movements during cognitive tasks. In the present study, we replicated the Simon effect, which is known as the “stimulus-response compatibility effect” in a Mouse tracking paradigm. We investigated the impact of design factors on Mouse-tracking data by placing the response alternatives at the bottom corners rather than at the top. We also performed an additional experiment, including the reverse Simon Effect. Consistent with previous studies, the mouse tracker experiments conducted in this thesis showed a significant stimulus-response compatibility effect while the response directions towards the left and right corners are not entirely symmetric in the conflict cases. On the other hand, switching the response mapping to top-to-bottom has increased the asymmetry between left and right cases during conflict trials. Lastly, the reversal effect was observed vividly in the case of y-flips, which seemed to be the best indicator for the process of adjusting to the new color-response pairing.

**Keywords:** Simon task, Simon effect, mouse tracking, cognitive processes stimulus-response compatibility effect

## ÖZ

### SİMON GÖREVİ SIRASINDA EL HAREKETLERİNİN DİNAMİKLERİNİN İNCELENMESİ

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Yüksek Lisans, Bilişsel Bilimler Bölümü

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Aralık 2019, 60 sayfa

Bilişsel sistemin bilgiyi gerçek zamanlı olarak nasıl işlediği, deneysel psikoloji ve bilişsel bilimler alanlarında önemli araştırma konularından bir tanesidir. Bilişsel işlem olgusunun farklı yönlerini araştırmak için bu güne kadar çeşitli ölçütler ve yazılım araçları önerilmiştir. Bu yöntemlerden biri olan fare izleyici, bilişsel görevler sırasında katılımcıların fare hareketlerini kaydederek araştırmacıların, motor tepkilerin dinamik açılımı hakkında veri toplamasına izin verir. Bu çalışmada “etki-tepki uyumluluk etkisi” olarak bilinen Simon etkisi fare izleyici yaklaşımı ile çeşitli koşullarda tekrarlanarak fare izleme yöntemiyle ne tür bilgiler elde edilebileceği incelenmiştir. Bu amaçla tepki alternatiflerinin sol/sağ üst köşelerden ziyade alt köşelere yerleştirildiği deney tasarım faktörlerinin fare izleme verileri üzerindeki etkisi incelenmiştir. Buna ek olarak, katılımcıların deneyin ortasına kadar belirli bir renk-yön ilişkisine (örneğin yeşil-sol ve kırmızı-sağ) maruz kaldığı, ve deney ortasında bu ilişkinin tersine çevrildiği tersine Simon etkisini içeren ek bir deney yapılmıştır. Önceki çalışmalarla uyumlu olarak, bu tezde yürütülen fare izleyici deneyleri, önemli bir uyaran-tepki uyumluluk etkisi gösterirken, sol ve sağ köşelere doğru verilen yanıtların uyumsuz durumlarda tamamen simetrik olmadığı gözlenmiştir. Öte yandan, yanıt eşlemesini yukarıdan aşağıya doğru değiştirmenin, uyumsuz denemeler sırasında sol ve sağ durumları arasındaki asimetriyi arttırdığı gözlenmiştir. Son olarak, tersine Simon etkisi deneyinde yeni renk-tepki eşleşmesine uyum sağlama süreci sırasında en belirgin etkinin y-ekseninde gözlenen dönüş sayısındaki değişim olduğu gözlenmiştir.

Anahtar Sözcükler: Simon görevi, Simon etkisi, fare izleyici, bilişsel süreçler, etki-tepki uyumluluk etkisi

To my beloved cousin and sister, Ayşe Belgin BAŞARAN



## ACKNOWLEDGMENTS

Firstly, I would like to thank my supervisor, Assist. Prof. Dr. Murat Perit akır. I can't thank him enough for his contribution. Without his support, guidance, and knowledge, this thesis would have never been completed. Every phase of this research, from the research topic to analyzing the findings, he generously gave of his time to better this thesis.

I would also like to thank my examining committee members, Assoc. Prof. Dr. Cengiz Acartürk and Assist. Prof. Dr. Murat Ulubay for their valuable reviews, comments, and their understanding.

I would also like to thank Pardis Fallahzadeh, who first introduced the MouseTracker Software and shared her knowledge and Malik Akdemir for his contribution and knowledge.

I would also like to thank my dearest friends, Ayşenur Hülügü, Burcu Taşdemir, Gamze elik, and Nuray Zeybek, for their endless support. I would also like to thank Sinan Onur Altınuç, who shared his knowledge generously throughout my study period.

I would also like to thank my cousins: İremnur Soyluoğlu and İlay Kadiroğlu for accompanying me to study. I would also like to thank Pınar Keskinocak and Bülent Başaran, for their endless support throughout my study period.

I would also like to thank my colleagues in Hatay Social Security Institution for their participation in my experiments. Mainly, Yunus Emre Karaca supported me through every phase of this research and Zeynep Kaplan, who always supported me.

I would also like to thank my colleagues; Tuğe Özmen, and Özgün Yasan for helping me to collect data.

Lastly, I would like to thank my family, especially my mother, Safiye İkizoğlu, and my sister Bahar Karadaş for their endless support.

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## LIST OF ABBREVIATIONS

<b>AUC</b>	The Area Under the Curve
<b>HCI</b>	Human Computer Interaction
<b>MD</b>	Maximum Deviation
<b>MD-Time</b>	Maximum Deviation Time
<b>PDDL</b>	Planning Domain Definition Language
<b>RT</b>	Reaction Time
<b>S-R</b>	Stimulus-Response



## **CHAPTER 1**

### **INTRODUCTION**

Understanding how the cognitive system processes information is one of the key concerns for researchers in cognitive science. Response time analysis has been one of the most popular methods used by researchers to probe into mental phenomena (Jastrow, 1890). Since the development of the subtraction method by Donders (1868/1969), carefully designed experiments that incrementally build on each other have been extensively used to tease out the time cost of targeted mental processes. Subjecting participants into experimental conditions that differ only in the presence of the targeted mental stage was typically involved in this approach. For instance, Donders (1969) proposed the use of simple reaction time (e.g. press the button when the stimulus is present), go/no-go reaction time (e.g. press the button only if target stimulus is present among two possibilities) and choice reaction time (e.g. press the left button if stimulus 1 is present and press the right button if stimulus 2 is present) tasks in an effort to derive a pure measure of the cost of stimulus discrimination time by subtracting the reaction time of task 2 from 1, and response choice by subtracting the reaction time of task 3 from 2, respectively.

Despite the rigor provided by such designs, the way participants change their response characteristics due to factors such as learning and speed-accuracy tradeoff provide challenges to this approach (Luce, 1986). The method also involves direct comparison of different tasks to account for a target process. More recent improvements over the subtraction method involve the Additive Factors approach (Sternberg, 1969), where different variants of the same task are considered for subtraction analysis, as opposed to comparing different but complementary tasks. This approach makes also some important assumptions about the nature of cognitive processes, such as (a) the time cost of certain events such as pressing a button takes the same amount of time regardless of the information that needs to be processed, (b) the total duration for a response is a sum of the time cost of sub-processes, and (c) measurement of time costs of smaller processes can be performed by dividing the time cost of a larger but measurable process (Sternberg, 1969). However, in complex processes like decision making its difficult to distinguish the motor execution of the response from the resolution of a conflict (e.g. stimulus-response compatibility), since the resolution could be resolved as the response is taking place (Scherbaum,

Dshemuchadse, Fischer & Goschke, 2010). Such issues have motivated the need for methodologies that can better trace the dynamical unfolding of such processes (Spivey & Dale, 2006; Spivey, 2008).

Mouse tracking recently emerged as an alternative methodology for capturing the dynamic unfolding of a motor response to a stimuli. Software packages and add-ons such as the MouseTracker (Freeman & Ambady, 2010) and Mouse Trap (Kieslich & Henninger, 2017) allow researchers to track the mouse movements continuously over time during tasks that require the processing of a stimuli and an execution of a response. For example, in a typical mouse tracking setup for the two-choice reaction paradigm, the stimulus is presented in the middle of the screen, whereas the responses are placed on the top left and right corners. During each decision trial, the participants are expected to move the mouse from a fixed initial position at the bottom towards their choice and click on the button to register their decision. In addition to the reaction time to click on a response button, mouse trackers also record the trajectory of the mouse cursor as it traveled from the starting point towards the response. This allows researchers to investigate various additional features of these trajectories that are not possible to study in typical reaction time recording setups including physical buttons.

Existing mouse tracking software tools provide several measures to capture the motor dynamics of the hand movements in the course of activities that have been traditionally studied in psychology by means of button presses. When the “outcome-based measures” are used, such as reaction times (RTs), the temporal information and mental activities’ continuous stream of real time dynamics data can be lost (Freeman & Ambady, 2010). The tasks which culminate in the same response times can be differentiated by the help of broader measures of “spatial attraction/curvature”, “complexity”, “velocity” and “acceleration” (Freeman & Ambady, 2010). Therefore, the temporal dynamics of mental activity which is leading to participants’ responses and continuous streams of cognitive output can be unveiled in real time with the help of Mouse dynamics.

In summary, “...hand in motion reveals mind in motion” (Freeman & Ambady, 2010, p.226) summarizes the rationale of the mouse tracking paradigm. In the traditional perspective, the motor responses are considered as endpoints of sensory and cognitive subsystems. Contrary to what is assumed in the classical reaction-time analysis perspective, the motor response is continuously adjusted by “perceptual-cognitive processing” over time. The motor responses are not the endpoints of cognitive processes, but they are the parts of “dynamics of perception and cognition”. Thus, if we sample the online motor responses fast enough, the motor responses can give a clue about the time in the course of perceptual-cognitive processing (Freeman & Ambady, 2010). This is especially important in the context of decision tasks where resolution of conflict unfolds and gets resolved online during the course of the response (Scherbaum et al., 2010).

Despite the many advantages offered by the mouse tracking paradigm, recent publications highlight the need for a careful investigation of methodological issues such as the influence of the positioning of stimulus and response box positions, as well as the choice of cursor speed, sampling rate and starting position on the mouse tracking measures (Schoemann, O'Hara, Dale & Scherbaum, 2019; Scherbaum & Kieslich, 2018). These studies called for practical conventions to standardize and design key parameters underlying a mouse tracking experiment design. The current study aims to contribute to these efforts by investigating additional factors such as handedness, the effects of switching the orientation of trajectories from bottom to top corners versus from the top to bottom corners, and the degree of symmetry among trajectories going left versus right directions, in the context of a mouse tracking version of a well known stimulus-response compatibility task called the Simon Task. For this purpose, a mouse tracking version of the Simon Task was implemented by using the Mouse Tracker software (Freeman & Ambady, 2010), which is known to elicit the expected effect as explored by previous research (Scherbaum et al., 2010). We replicated the original design of Scherbaum et al. (2010) and then contrasted the findings with a modified version of the same task where the response buttons were placed at the bottom corners rather than to the top as opposed to the Scherbaum et al.'s design. We also performed an additional experiment including the reverse Simon Effect, where the participants were first exposed to a specific color-direction association (e.g. green-left and red-right), which was flipped in the middle of the experiment in an effort to observe the perturbation caused by this change on conflict resolution dynamics.



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Simon Effect**

The Simon effect, which is well-known as a "stimulus-response compatibility effect", is popular in psychology and cognitive science history because it is heuristic as a tool rather than a phenomenon. The Simon task raises theoretical questions which are investigated by the help of its straightforward design (Hommel, 2010).

A huge array of studies can be seen in the chronological evolution of the Simon effect. In the article, which was published in 1963, Simon and Wolf presented a study about the "choice reaction time task". In this study, the experiment consisted of two stimulus lights with five different orientations and two response keys. This study showed that spatial cues between the stimulus lights and response keys shorten the reaction time. According to this article, some of the earlier studies about the "spatial stimulus response correspondences" are: Morin and Grand's (1955) "changing the connections of the stimulus lights and response keys" study; Anderson, Grand and Nystrom's (1956) "reorganizing the location of display and control consoles" study; and Nystrom and Grands' (1955) "changing angular locations of the stimuli rather than response" study (Simon & Wolf, 1963). One of the earlier studies is the "S-R Compatibility: Correspondence among paired elements within stimulus and response codes" by Fitts and Deninger (1954). This article mentions about how the participants were asked to move the stylus according to the circular array of lights in one of eight locations. In the stimulus-response compatible cases, the participants performed better (Fitts & Deninger, 1954; Gok, 2016).

In 1967, Simon and Rudell presented another study which was about Auditory S-R compatibility. In the task, the auditory stimuli (left or right) were presented to the participants' left or right ear. The task was designed to press the left or right keys, not considering the ear position, but the meaning of the words (left or right) (Simon & Rudell, 1967; Gok, 2016). The result of this study was that the reaction times were faster when the participants heard the "left" stimulus in the left ear

than when the "left" stimulus was heard in the right ear or vice versa. (Simon & Rudell, 1967).

Another study is about the Simon Task where movement trajectories are used to investigate the time course of the Simon effect study (Buetti and Kerzel, 2008). In this research, Buetti and Kerzel (2008) conducted three experiments designed in the horizontal surface. The temporal and spatial dynamics of the responses for the vertical and horizontal placed trials (congruent vs incongruent) were collected. The Simon effect was observed in three experiments including horizontal, vertical, and acoustic stimuli. Based on the result, the horizontal visual stimuli's reaction time was lower than the visual vertical and acoustic horizontal stimuli's collected reaction times. The conclusion of the study presented consistent results as the previous one. The stability of the time course of the Simon effect in RTs was observed when applied in vertical visual and horizontal acoustic stimuli (cognitive Simon tasks). However, it was reduced with horizontal visual stimuli (visuomotor Simon task). Conversely, the Simon effect in motor parameters reduced the RT-bins in all situations.

## **2.2 Human Computer Interaction**

The general and simplified definition of the term the human-computer interaction is that "it is the study of the interaction between humans and computers" (Booth,1989/2014, p.4). There is a lot of research in Human Computer Interaction area to fill the gap between the theory and implementation. These studies try to link the theory and implementation with respect to psychology which is based on cognitive theory of skilled human-computer interaction. The range of fields such as cognitive psychologists, computer scientists, system designers, human factors specialists, ergonomists, and human engineers have shared interests in the human computer interaction area. The theory and empirical methods can be tied in the domain of human computer interaction by extending the analysis of a real-world domain. The essential point in designing Human Computer Interaction is that knowing the user opens the path to design better human computer interfaces (Hansen,1971; Card, Moran & Newell,1983).

According to the perspective that views the human mind as an information processing system, the model human processor consists of three interactive systems including the perceptual, motor and cognitive systems (Card, Moran & Newell, 1983). The information flow in these interactive systems can be described by using the methodology of cognitive psychology. The information can be taken by the perceptual system sensors known as the Visual Image Store and Auditory Image Store. The cognitive system takes the coded information from the perceptual systems' stored sensory image in working memory which holds information under current circumstances. Then, the previously stored information in the long-term memory which stores knowledge for future use is applied to convey the information to the motor system. According to the Card, Moran and Newell (1983); the model human processor acts as a serial processor in some tasks such as pressing a key which response with a light. However, the



model human processor acts as an integrated and parallel processor in other tasks such as typing, reading, etc. which is interacting as three subsystems working simultaneously. Briefly, the physical world is detected by the cognitive system by means of perceptual system's information flow into a working memory which activates long-term memory. After "recognize-act cycle of the cognitive processor", the thought translated into an action by motor processor. According to the Card and his colleagues, the motor systems' movement is not continuous, but it contains discrete micro movements (Card, Moran & Newell, 1983).

In the Human Computer Interaction area, Fitts's law has an important place, which is displayed in Equation 2.1 below (Fitts, 1984; Card, Moran & Newell, 1983).

$$T_{pos} = K_0 + I_M \log_2(D/S + .5) \text{sec}, \quad (2.1)$$

where  $T_{pos}$  = Positioning time,  
 $D$  = Distance to the target,  
 $S$  = Size of the target,  
 $I_M$  = .100[.070~.120]sec/bit, and  
 $K_0$  = a constant

Equation 2.1. Fitts's law (Retrieved from "Psychology of human computer interaction" p. 241).

Fitts' law helps us to predict positioning time ( $T_{pos}$ ). The important parameter is in this law is "D" distance and "S" the width of the target. The slope ( $I_M$ ) and constant ( $K_0$ ) are determined experimentally (Fitts, 1954; Card, Moran & Newell, 1983). To recapitulate, if the target is farther away and has a smaller size, it is more difficult to click on. If the target's distance decreases while the target's width increases, then selecting the target becomes much easier for the participant.

Another law which is essential in the Human Computer Interaction area is the "Power Law of Practice." (Card, Moran & Newell, 1983). We assume that the more practice we have, the less time is needed to complete the task. Snoddy (1926) who first noticed the relationship between practice and the time to complete task (Snoddy, 1926; Card, Moran & Newell, 1983). The power law can be seen as follows:

*"The time  $T_n$  to perform a task on the  $n$ th trial follows a power law:*

$$T_n = T_1 n^{-a}, \quad (2.2)$$

*where  $a = .4$  [.2~.6]."*

Equation 2.2. The power law of practice (Retrieved from “Psychology of human computer interaction” pg. 27).

The Power Law of Practice shows that; the time to complete the task decreases linearly with practice.

In his book “The Continuity of Mind,” Spivey (2008) opposes the traditional information processing approach of cognitive psychology by arguing that “the external discreteness of the actions” does not necessarily imply the “internal discreteness of the mental representations” (Spivey, 2008, p.3). He focuses on the continuous trajectories between the set of possible probabilistic high-dimensional brain states rather than focusing on discrete mental state representations (Spivey, 2008). Due to the state space dynamics rather than phase space dynamics, eye and mouse tracking experiments have an utmost importance for proving mental trajectories’ semi-continuous visualization as experimental evidence. The experiments show us how mental trajectories’ high-dimensional internal state space gets transformed as evidenced in the form of mouse trajectories in two-dimensional space. From mouse trajectories data, we can track where the attention is directed and how the mouse trajectories’ data source shows the continuous information flow from mental activity to motor activity (Spivey, 2008).

### **2.3 Mouse Tracking Studies**

Scherbaum, Dshemuchadse, Fischer and Gosche’s (2010) spatial conflict task research is one of the initial studies which combines the Simon Task with a mouse tracking paradigm. They investigated the effect of a previous trial on the following trial. For this purpose, they conducted two experiments. The results set forth that, the onset of following a trial’s trajectory was influenced by the response of the previous one. However, the later part of the trajectory was influenced by the degree of both current conflict trial and the previous one.

Among the other outcome-based measures such as RTs or error rates, reaction time is a golden measure in many research areas (Freeman & Ambady, 2010). However, when the reaction time is used, continuous stream of the temporal information data can be lost. Mouse tracking tools help the researchers to go beyond the outcome measures collected data. Mouse tracking methods focus the psychological process by capturing the motor dynamics of hand movements by means of the measures such as “spatial attraction/curvature”, “complexity”, “velocity” and “acceleration” (Kieslich, Henninger, Wulff, Halsberg and Mecklenbeck, 2018; Freeman & Ambady, 2010). The measures which can be computed by means of Mouse Tracker Software’ data are; the maximum deviation (MD), maximum deviation time(MD-Time), area under the

curve(AUC), x-flips and y-flips. The definition of these measures are provided in the following respectively. Firstly, the maximum deviation is a perpendicular deviation from idealized straight line between the start and end of trials. So, a maximum deviation is a perpendicular line which is drawn between the vertex of observed trajectory to the idealized one (Freeman & Ambady, 2010). Another variable, MD-Time, is recorded in milliseconds and it measures the average time of the arrival of the cursor at the vertex of the maximum deviation in each mouse trajectory. Another one, the AUC is the geometrical area between the observed trajectories and the idealized straight line which is considered between the start and the endpoint of responses. The Figure 2.1 shows the measures; AUC and MD (Freeman& Ambady, 2010).

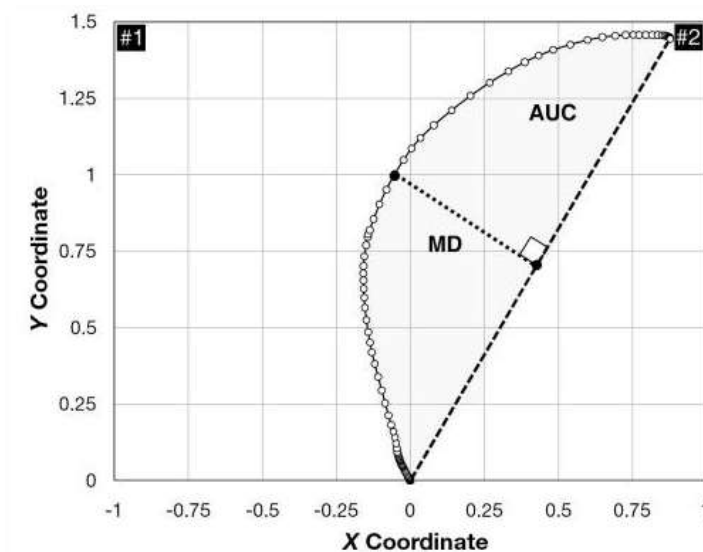


Figure 2.1 Representations of MD& AUC in the standard coordinate space of MouseTracker software. Graph from John Freeman and Ambady, MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method, (Behavior research methods, 2010), 229. Print.

It is important to measure the complexity of the mouse trajectories. For measuring the complexity, the x-flips counts the number of turn-rounds of the direction along the x-axis. Another measure for complexity is the y-flips. When it is compared to x-flips, y-flips counts how many turn-rounds occur along the y-axis. The instabilities of the participant's response can be measured with the help of the x-flips and y-flips. Particularly, y-flips can measure how the unselected response attracts the participants in the case where response alternatives on the top or bottom. (Freeman& Ambady, 2010).

Mouse Tracker software consists of three programs, including Runner, Designer, and Analyzer. The Designer is used to set up visual layout and response options of an experiment (Freeman and Ambady, 2010). There are different methodological setups on Mouse Tracker. One can set the number of response alternatives with their location and size and also a visual stimulus (can be a string

of letters, an image, or sound). In addition to these, one can also set the starting conditions. Thus, there are different methodological options. It is crucial to investigate how these methodological differences affect the results of mouse-tracking studies.

One of the studies which investigates methodological variation between conditions; the static starting condition and the dynamic starting condition. In that study, the mouse-tracking version of Simon Task was used to investigate how the methodological setup impacts the mouse-tracking measures. The result of this methodological study suggests that within trial continuous measures should be applied to dynamic starting procedures in order to assess better mouse movements mirroring the cognitive process (Scherbaum & Kieslich, 2017).

The other studies which investigate methodological issues on the Mouse tracking paradigm are the influence of the positioning of stimulus and response box positions, the choice of cursor speed, sampling rate and starting position on the mouse tracking measures (Schoemann, O'Hara, Dale & Scherbaum, 2019; Scherbaum & Kieslich, 2018). These studies called for an investigation of methodological issues to standardize and design key parameters underlying a mouse-tracking experiment design. The current study aims to contribute to these efforts by investigating the effects of switching the orientation of trajectories from bottom to top corners versus from the top to bottom corners in the context of a mouse tracking version of Simon Task. The Simon Task, which explored by previous research (Scherbaum et al., 2010), was replicated with the help of Mouse Tracker software. A modified version of the same task where the response buttons were placed at the bottom corners rather than to the top as opposed to the Scherbaum et al.'s design was also performed to contrast the findings to contribute the methodology of the mouse tracking paradigm. The reverse Simon effect was also performed by first associating red and green colors to specific response directions through repeated trials, and then switching the mapping to reinforce the other way around to observe the perturbation caused by this change on conflict resolution dynamics.

## **CHAPTER 3**

### **MATERIALS AND METHODS**

In this chapter, the method and materials are explained. The Simon Task was applied with the Mouse Tracker software to replicate the Simon effect. We went further in our analysis by exploring dynamic complexity of the mouse trajectories rather than exploring only response time analysis. In the present study, three experiments were conducted to get insights into the Simon effect with the help of a rich set of indicators provided by the mouse tracking paradigm.

#### **3.1 Experiment 1**

##### **3.1.1 Participants**

In experiment 1, 52 Turkish-speaking subjects, 37 male and 15 female, aged between 20 and 56 ( $M=28.21$ ,  $SD=7.05$ ), participated in the experiment. The participants were selected by a simple random sampling method, and they volunteered to participate in the study. The experiment was approved by the METU Human Subjects Ethics Committee. Prior to the experiment informed consent of the participants were obtained. No information about the aim of the study was provided before the experiment, only short information about the tasks in the experiments were provided. Handedness was measured by using a Turkish version of the Edinburgh Handedness Inventory (R.C. Oldfield, 1970). According to the handedness test, 47 out of 52 participants (94%) were classified as right dominant. Handedness was not used as an exclusion criteria. Although the participants' handedness score was indicated that they were left-hand dominant, they used the Mouse by their right hand. Only 2 out of 5 left-hand dominant participants controlled the mouse by their left-hand.

##### **3.1.2 Experiment setup**

The experiment was designed using the MouseTracker Software which was run on an 15.6-inch Acer-PC running Windows 10. A standard computer mouse, Logitech M105, was used to record the mouse movements. The MouseTracker has three

programs itself: Runner, Designer and Analyzer. The experiment was designed using the graphical user interface called the Designer, to set up visual layout and response options of an experiment. (Freeman & Ambady, 2010). The standard two-choice selection task was used to design the experiment. The MouseTracker's coordinate space where all experiments operated in is a standard space represents a 2 by 1,5 rectangle (Freeman and Ambady,2010). In this experiment, the coordinates of "Start" button was placed at -0,2 and 0,1 on the x-axis and y-axis, respectively. On each trial, "Başlangıç" (Start) button was placed on the bottom-center of the screen and the trial began after the participants clicked on the start button. The coordinates of response alternative "sol" button was placed at -1 and 1,5 on the x-axis and y-axis, respectively. The other response alternative "sağ" was placed at 0,68 and 1,5 on the x-axis and y-axis, respectively. The display parameters and response options were edited using comma-seperated-value (.csv) files. When the experiments started, the instructions were given in the full screen image file. On each trial, "Başlangıç" (Start) button was placed at the bottom-center of the screen and the trial began after the participants clicked on the start button. The visual stimulus was arranged as a string of characters in Turkish such as sağ (right) and sol (left). The string of characters, which were screened on a black background in white, was displayed on either the right side or the left side of the plus symbol. The stimulus order was randomized. The response buttons, "sağ" (right) and "sol" (left), were displayed between trials constantly during the experiment. The visual stimulus- in this case the sağ (right) and sol (left)- appeared after the participant had clicked on the "start" button. At the start of every trial, the mouse cursor was automatically relocated to the start button. After clicking the button, the participants could move the mouse immediately. The hover mode is off, which means that when the participant's cursor goes to one of the response alternatives' location, the actual click is required to select one of the response alternatives. No time deadline was set for the participants' responses. The trajectories of the mouse sampled at 60-75 Hz, which means the real-time development of responses from the start button and to the target recorded approximately 60-75 times every second during the task.

### **3.1.3 Task**

The experiment was performed in two parts. The first part was consisted of four training trials to familiarize the participants to the task and the use of the mouse to register their responses. As soon as the first part finished, the participants started the second part of the experiment which had sixty trials. A standard two-choice selection task was used for the experiment, which was conducted in Turkish.

In the first experiment; when the participants see the "Sol" (Left) text, regardless of whether the stimulus is on the left or right of the fixation cross in the middle, they were asked to move the mouse cursor to the upper left corner as soon as possible. When they see the "Sağ" (Right) text, regardless of whether the stimulus is on the left or right side of the fixation cross, they were asked to move the mouse cursor to

the upper right corner as soon as possible. The participants were verbally warned not to pick up the mouse from the table. It was necessary for the mouse to remain in contact with the table throughout the experiment in order to accurately record its movements. The stimulus, which was located on the left or right of the fixation cross located on the center of the screen, was displayed as soon as the participants clicked the start button. The click on the start button also initialized the position of the mouse cursor in the center of the start button.

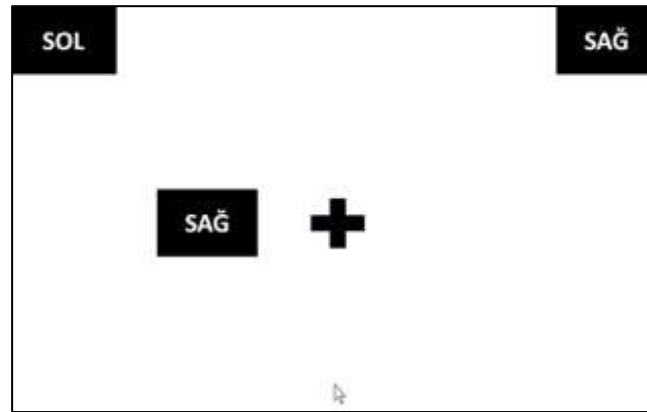


Figure 3.1 One example of screen layouts of the first experiment

## 3.2 Experiment 2

### 3.2.1 Participants

In the second experiment 52 Turkish-speaking subjects (38 male and 14 females), aged between 18 and 50 ( $M=25.34$ ,  $SD=7.48$ ), participated in the experiment. Similar to experiment 1, the participants read and signed the informed consent form which was approved by METU Human Subjects Ethics Committee, and they also completed the Turkish version of the Edinburgh Handedness Inventory. The experiment was applied to selected participants where a simple random sampling method was used. The participants were volunteered for the experiment. Before the experiment started, they were unaware of the aim of the study. However, the participants just got short information about the tasks. According to the handedness test, 44 (84%) right-handed and 8 (16%) left-handed subjects participated in the second experiment. Although the participants' handedness score indicated that they were left-hand dominant, they used the computer mouse by their right hand. Only 2 out of 8 left-hand dominant participants used their left-hand to control their mouse movements.

### 3.2.2 Experiment setup

The experiment was designed using MouseTracker Software which was run on a 15.6-inch Toshiba-PC running Windows 8. Similar to experiment 1, Logitech M105 was used to record the mouse movements. The Mouse Tracker software's graphic-based program, the Designer was used to design the experiment. Two choice selection task was used the same as in the first experiment. However, distinctly from the first experiment, the response alternatives' location was turned upside down. The start and response buttons were designed using the Designer. The MouseTracker's coordinate space where all experiments operated in is a standard space represents a 2 by 1,5 rectangle (Freeman and Ambady,2010). The coordinates of "Start" button was placed at -0,18 and 1,5 on the x-axis and y-axis, respectively. On each trial, "Başlangıç" (Start) button was placed at the top-center of the screen and the trial began after the participants clicked on the start button. The coordinates of response alternative "sol" button was placed at -1 and 0,24 on the x-axis and y-axis, respectively. The other response alternative "sağ" was placed at 0,68 and 0,25 on the x-axis and y-axis, respectively.

The experiments started with the instructions which were given in full screen image file. After the instruction part, the experiment started as soon as the participants click on "Başlangıç" (Start) button, which were placed at the top center of the screen. The visual stimulus was arranged as a string of characters in Turkish such as sağ (right) and sol (left). The string of characters, which were screened on a black background in white, was randomly displayed on either the right side or the left side of the plus symbol. The plus symbol is placed at the middle center of the screen whose coordinate is at 0 on the x-axis and at 0,7 on the y-axis. The response buttons, "sağ" (right) and "sol" (left), were displayed between trials constantly during the experiment. The visual stimulus- in this case the sağ (right) and sol (left)- appeared after the participant had clicked on the "start" button. At the start of every trial, the mouse cursor was automatically relocated to the start button. Similar to the first experiment, the hover mode was off and no time deadline was set for the participants' responses. The trajectories of the mouse sampled at 60-75 Hz.

### 3.2.3 Task

The experiment 2 is consisted of two parts. The first part of the experiment is a familiarization part which had four trials. As soon as the familiarization part finished, the participants started the experiment 2 which consisted of sixty trials, like the first experiment.

In the second experiment; when the participants see the "Sol" (Left) text, regardless of whether the stimulus is on the left or right of the fixation cross at the center, they were asked to move the mouse cursor to the bottom left corner as soon as possible. When they see the "Sağ" (Right) text, regardless of whether the stimulus is on the left or right of the fixation cross at the center, they were asked to move the mouse cursor to the bottom right corner as soon as possible. The participants warned not to



pick up the mouse from the table to keep the mouse in contact with the table throughout the experiment so as to accurately record its movements.

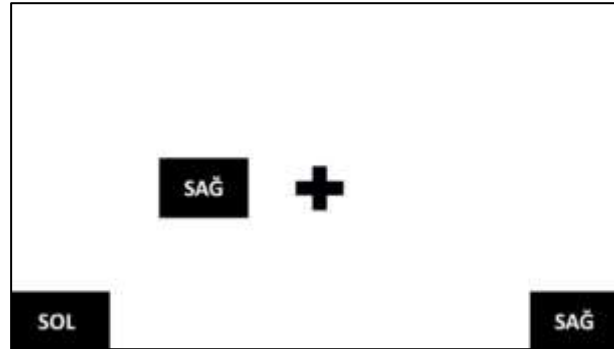


Figure 3.2 One example of screen layouts of the second experiment

### 3.3 Experiment 3

#### 3.3.1 Participants

In the experiment 3, 73 Turkish-speaking subjects, 44 male and 29 female, aged between 18 and 44 ( $M=26.71$ ,  $SD=6.78$ ), participated in the experiment. The same procedure as in the experiment1 & experiment2 was applied. According to the handedness test, 65 out of 73 (89%) of the participants in the third experiment were right dominant. Only 3 participants used their left-hand to control their mouse movements. The other participants, whose handedness score indicated that they were left-hand dominant, used their right-hand to control their mouse movements.

#### 3.3.2 Experiment setup

The experiment was designed using MouseTracker Software which was run on a 15.6-inch Toshiba-PC running Windows 8. As in the first two experiments, Logitech M105 was used to record the mouse movements. The same two-choice selection task was employed in the third experiment. The only difference was the use of a color-based version with the colors green and red to encode direction, which replaced the verbal referents “sağ” and “sol”.

### 3.3.3 Task

Experiment 3 is consisted of two parts. Similar to Experiment 1 and Experiment 2, the first part of experiment is a familiarization part which had four trials. As soon as the familiarization part finished, the participants started the experiment 3 which includes 32 trials in the first part and 32 in the second part. This experiment was conducted to observe the reverse Simon effect.

In this experiment; when the participants see the “green” box, regardless of whether the stimulus is on the left or right of the fixation cross at the center, they were asked to move the mouse cursor to the top left corner where the green box was presented, as soon as possible. When they see the “red” box, regardless of whether the stimulus is on the left or right of the fixation cross at the center, they were asked to move the mouse cursor to the top right corner where the red box is presented, as soon as possible.

As soon as the participants finished the first part, the second part of the experiment was conducted where the color mapping was reversed. In the second part of the experiment, the participants were asked to click on response buttons according to the color of the stimulus. In particular, If they see the “red” box, regardless of whether the stimulus is on the left or right of the fixation cross, they were asked to move the mouse cursor to the top left corner where the red box is presented, as soon as possible. However, if they see the “green” box, they were asked to move the mouse cursor to the top right corner where the green box presented, as soon as possible. The screen layouts of the experiments were shown in the Figure 3.4. The participants warned not to pick up mouse from the table to keep the mouse in contact with the table’s surface throughout the experiment in order to accurately record its movements. The participants self-reported that they are not color-blind.

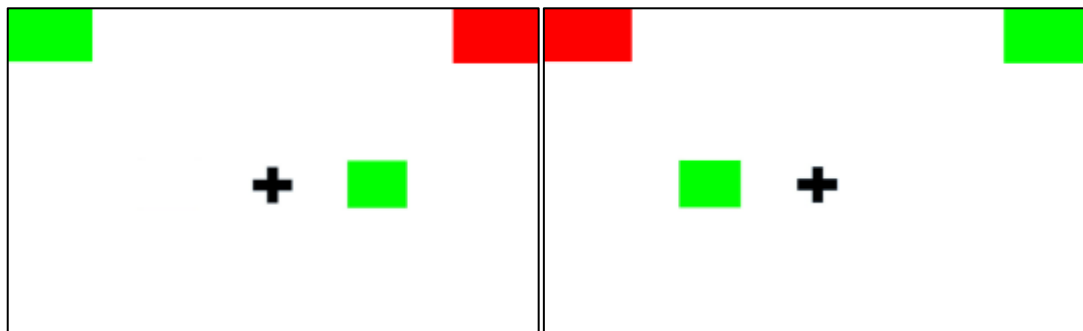


Figure 3.3 The examples of screen layouts of the first part and second part of third experiment, respectively.

## CHAPTER 4

### RESULTS

#### 4.1 Results of the Experiment 1

##### 4.1.1 Reaction Time (RT)

In the current study; there was a significant main effect of the condition on reaction time (RT) ,  $F(1, 51) = 49.91$ ,  $p < .001$ , partial  $\eta^2 = .49$  . The main effect of position,  $F(1, 51) = 1.65$ ,  $p > .05$ , and the interaction effect,  $F(1, 51) = 0.046$ ,  $p > .05$  , were not significant.

Table 4.1 The ANOVA results for Reaction Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	369577,774	1	369577,774	49,910	,000	,495
position	15154,256	1	15154,256	1,647	,205	,031
condition * position	273,771	1	273,771	,046	,832	,001

When 5 participants who were left-hand dominant according to the Edinburgh Handedness Inventory were excluded from the sample, the results were not affected. The main effect of condition was significant,  $F(1, 46) = 44.07$ ,  $p < .001$ , partial  $\eta^2 = .49$ , whereas the main effect of position,  $F(1, 46) = 1.73$ ,  $p > .05$ , and the interaction,  $F(1, 46) = .016$ ,  $p > .05$  were not significant.

Table 4.2 The ANOVA results for reaction time (the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	329787,522	1	329787,522	44,071	,000	,489
position	15189,828	1	15189,828	1,732	,195	,036
condition * position	97,954	1	97,954	,016	,901	,000

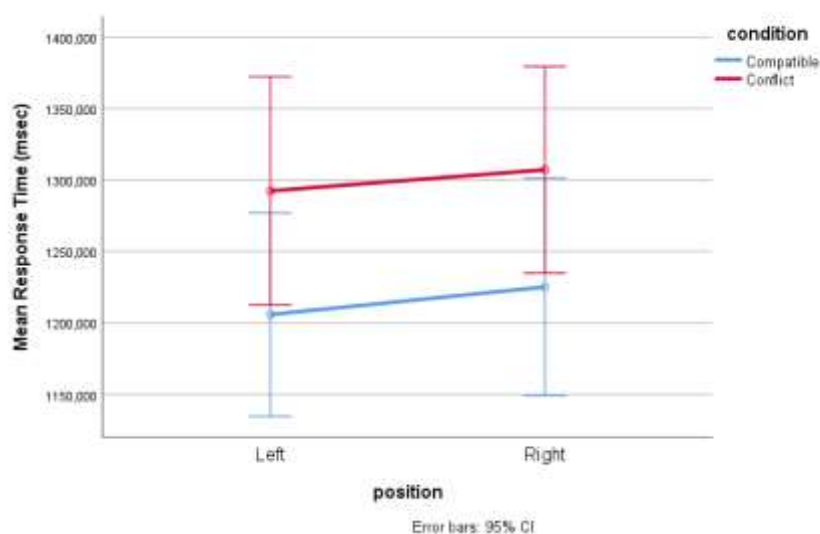


Figure 4.1 The line chart of RT which included error bars (all participants included)

#### 4.1.2 Maximum Deviation (MD)

In the current study; there was a significant main effect of condition on MD,  $F(1, 51) = 81.14$ ,  $p < .001$ , partial  $\eta^2 = .61$ . The main effect of position was not significant,  $F(1, 51) = .77$ ,  $p > .05$ . Contrary to the case of response time, there was a significant interaction between condition and position,  $F(1, 51) = 4.54$ ,  $p < .05$ , partial  $\eta^2 = .08$ .

Table 4.3 The ANOVA results for maximum deviation (MD)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
<b>condition</b>	5,113	1	5,113	81,142	,000	,614
<b>position</b>	,011	1	,011	,769	,385	,015
<b>condition *</b> <b>position</b>	,041	1	,041	4,545	,038	,082

When the sample is limited to right-handed people the main effect of condition,  $F(1, 46) = 89.90$ ,  $p < .001$ , partial  $\eta^2 = .66$ , and the interaction effect slightly increased,  $F(1, 46) = 5.88$ ,  $p < .01$ , partial  $\eta^2 = .11$ . There was still no difference with respect to position.

Table 4.4 The ANOVA results for maximum deviation (MD) (the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
<b>condition</b>	5,086	1	5,086	89,902	,000	,662
<b>position</b>	,019	1	,019	1,287	,263	,027
<b>condition *</b> <b>position</b>	,055	1	,055	5,885	,019	,113

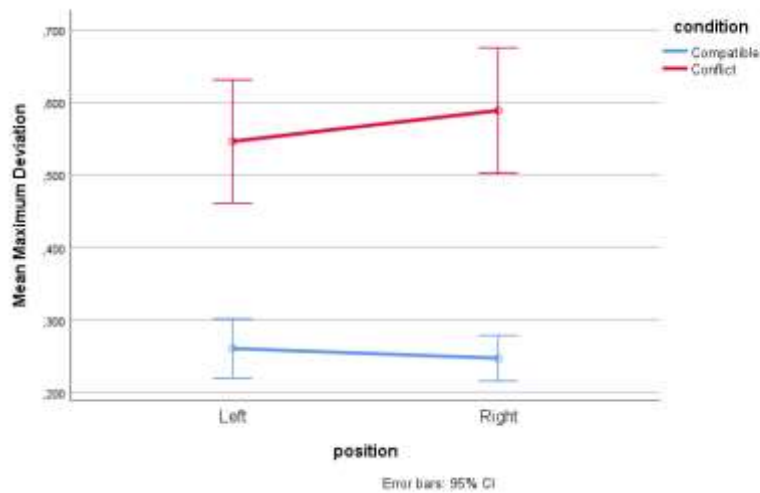


Figure 4.2 The line chart of MD which included error bars (all participants included)

#### 4.1.3 Maximum deviation time (MD-time)

In the current study; there was a significant main effect of condition on MD-time,  $F(1, 51) = 21.17$ ,  $p < .001$ , partial  $\eta^2 = .29$ . The main effect of position,  $F(1, 51) = 1.63$ ,  $p > .05$ , and the interaction effect,  $F(1, 51) = .09$ ,  $p > .05$ , were not significant.

Table 4.5 The ANOVA results for maximum deviation time (MD-time)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	103610,780	1	103610,780	21,170	,000	,293
position	5654,625	1	5654,625	1,633	,207	,031
condition * position	354,778	1	354,778	,088	,769	,002

When the analysis is restricted to right-handed participants only, the results did not change. The main effect of condition was still significant,  $F(1, 46) = 18.49$ ,  $p < .001$ , partial  $\eta^2 = .29$ , whereas the main effect of position,  $F(1, 46) = 1.31$ ,  $p > .05$ , and the interaction,  $F(1, 46) = .41$ ,  $p > .05$ , were not significant.

Table 4.6 The ANOVA results for maximum deviation time(the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	96114,658	1	96114,658	18,488	,000	,287
position	4797,602	1	4797,602	1,308	,259	,028
condition * position	1710,108	1	1710,108	,407	,527	,009

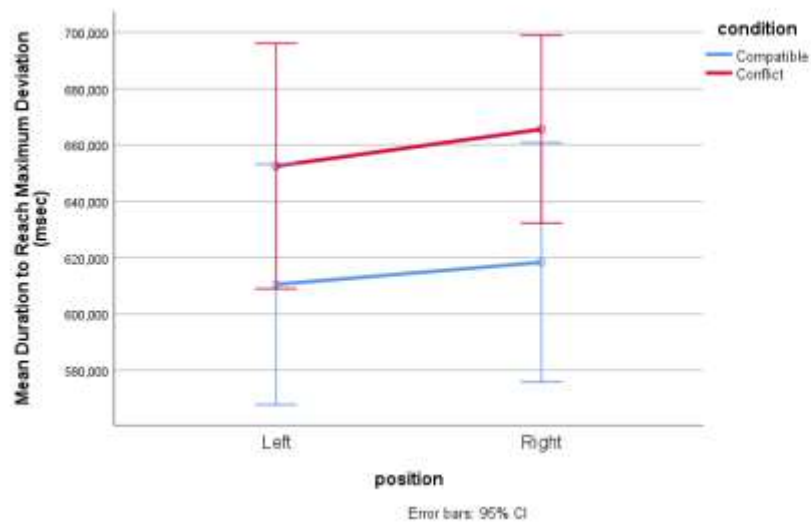


Figure 4.3 The line chart of MD-Time which included the error bars

#### 4.1.4 The Area under the Curve (AUC)

In the current study, since the distribution of AUC values were significantly right-skewed, a logarithmic transformation was first conducted. Since the resulting values satisfied the parametric assumptions, a 2x2 repeated measures ANOVA was conducted on the log-transformed AUC values. The results indicated that there was a significant main effect of condition,  $F(1, 51) = 108.46$ ,  $p < .001$ , partial  $\eta^2 = .68$ . The main effect of position,  $F(1, 51) = .10$ ,  $p > .05$ , and the interaction effect,  $F(1, 51) = 1.27$ ,  $p > .05$ , were not significant.

Table 4.7 The ANOVA results for the area under the curve (AUC)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	11,648	1	11,648	108,463	,000	,680
position	,006	1	,006	,097	,756	,002
condition * position	,045	1	,045	1,268	,265	,024

The effect size slightly increased when the sample was restricted to right-hand dominant participants. In this case, the main effect of condition,  $F(1, 46) = 116.35$ ,  $p < .001$ , partial  $\eta^2 = .72$ . The main effect of position and the interaction effect remained to be insignificant.

Table 4.8 The ANOVA results for area under the curve (the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	11,490	1	11,490	116,351	,000	,717
position	,000	1	,000	,007	,936	,000
condition * position	,089	1	,089	2,401	,128	,050



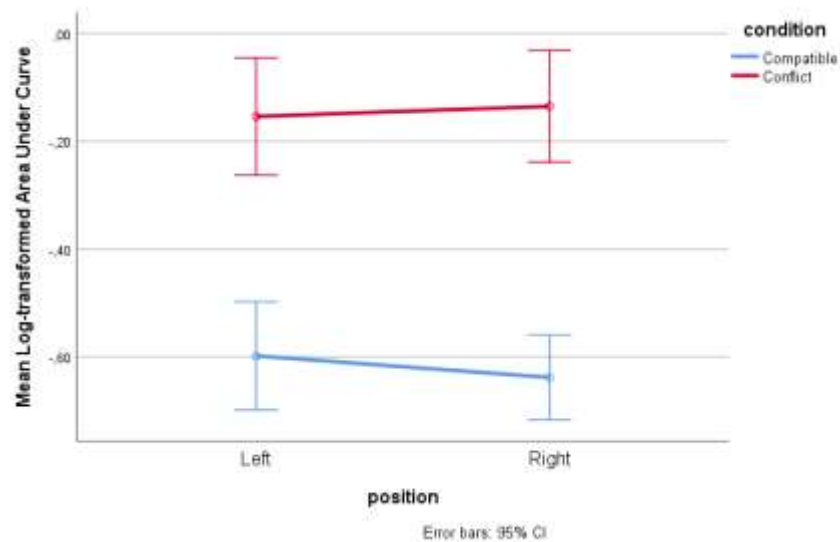


Figure 4.4 The line chart of log-AUC including error bars

#### 4.1.5 X-Flips

In the current study; there was a significant main effect of condition on x-flips,  $F(1, 51) = 20.08$ ,  $p < .001$ , partial  $\eta^2 = .28$ . The main effect of position,  $F(1, 51) = 3.09$ ,  $p > .05$ , and the interaction effect,  $F(1, 51) = .68$ ,  $p > .05$ , were not significant. Reducing the sample to the right-handed participants did not make any changes on the mean x-flip counts observed at each condition.

Table 4.9 The ANOVA results for the X-flips

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	10,784	1	10,784	20,083	,000	,283
position	2,161	1	2,161	3,090	,085	,057
condition *	,524	1	,524	,676	,415	,013
position						

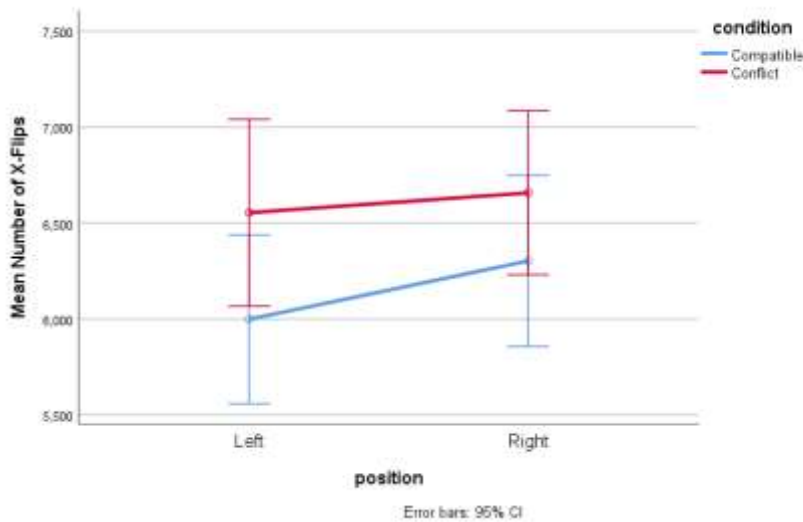


Figure 4.5 The line chart of x-flips included error bars (all participants included)

#### 4.1.6 Y-Flips

In the current study; there was a significant main effect of condition on y-flips,  $F(1, 51) = 39.38$ ,  $p < .001$ , partial  $\eta^2 = .44$  and a significant main effect of position,  $F(1, 51) = 5.96$ ,  $p < .05$ , partial  $\eta^2 = .10$ . The interaction effect was not significant,  $F(1, 51) = 2.32$ ,  $p > .05$ .

Table 4.10 The ANOVA results for the Y-Flips

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	28,727	1	28,727	39,382	,000	,436
position	3,121	1	3,121	5,960	,018	,105
condition * position	1,053	1	1,053	2,318	,134	,043

When the analysis restricted to right-handed subjects the effect sizes for the main effect of condition ( $F(1, 46) = 40.60$   $p < .001$ , partial  $\eta^2 = .47$ ) and position ( $F(1, 46)$

= 7.69,  $p < .01$ , partial  $\eta^2 = .14$ ) were slightly increased. The interaction effect remained to be insignificant.

Table 4.11 The ANOVA results for the Y-Flips (the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	29,642	1	29,642	40,602	,000	,469
position	3,938	1	3,938	7,691	,008	,143
condition * position	,962	1	,962	1,939	,170	,040

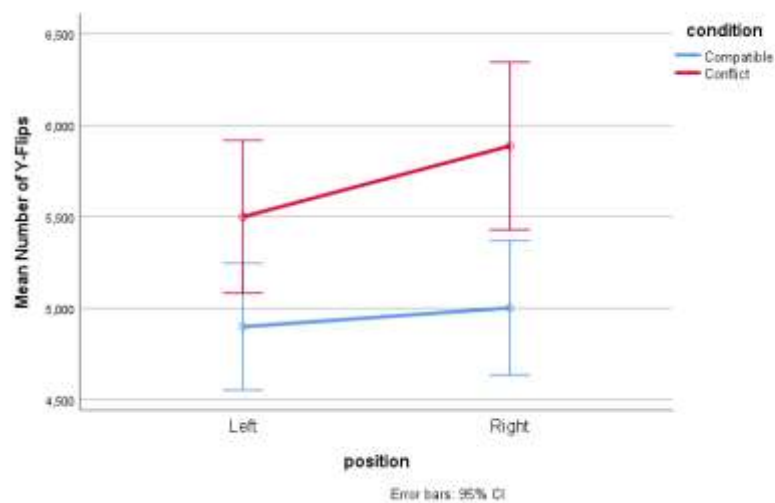


Figure 4.6 The line chart of y-flips included the error bars (all participants included)

#### 4.1.7 The Ratio of the Maximum Deviation and the Area under the Curve

In the current study; there was a significant main effect of condition on the ratio of the maximum deviation and the area under the curve,  $F(1, 51) = 63.17$ ,  $p < .001$ , partial  $\eta^2 = .55$ . The main effect of position  $F(1, 51) = 1.81$ ,  $p > .05$ , and the interaction effect  $F(1, 51) = 1.06$ ,  $p > .05$ , were not significant.

Table 4.12 The ANOVA results for the ratio of the maximum deviation and area under the curve

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	4,056	1	4,056	63,174	,000	,553
position	,115	1	,115	1,808	,185	,034
condition * position	,031	1	,031	1,062	,308	,020

When the analysis was restricted to right-handed subjects the effect size for the main effect of condition ( $F(1, 46) = 58.98$   $p < .001$ , partial  $\eta^2 = .56$  was slightly increased. The interaction effect and the main effect of position remained to be insignificant.

Table 4.13 The ANOVA results for the ratio of the maximum deviation and area under the curve (the left-hand dominant participants were excluded from the sample)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
condition	3,788	1	3,788	57,995	,000	,558
position	,066	1	,066	1,038	,314	,022
condition * position	,066	1	,066	2,192	,146	,045

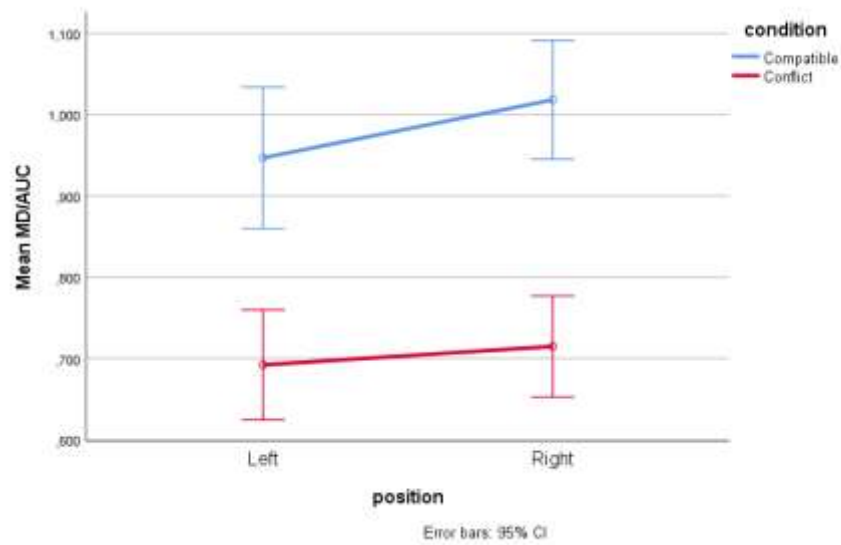


Figure 4.7 The line chart of ratio of MD and AUC included the error bars (all participants included)

#### 4.1.8 Error

In the current study; the incorrect response is selected in only 5 of the trials. The trials which ended with incorrect responses were all in the conflict cases.

#### 4.1.9 Normalized Time

In the recorded mouse tracker data; each trajectory has a different length of coordinate pairs. So, the time normalization is a necessity to get averaging rates and to make a comparison between the trials which have different length. After the time normalization, each trajectory had the same number of time steps (by default 101-time step including 100 equal spaces which is time normalized). In the current study, the 101-time step time normalization was applied for the recorded trajectory data. The time-normalized data can be seen in Figure 4.8 & 4.9

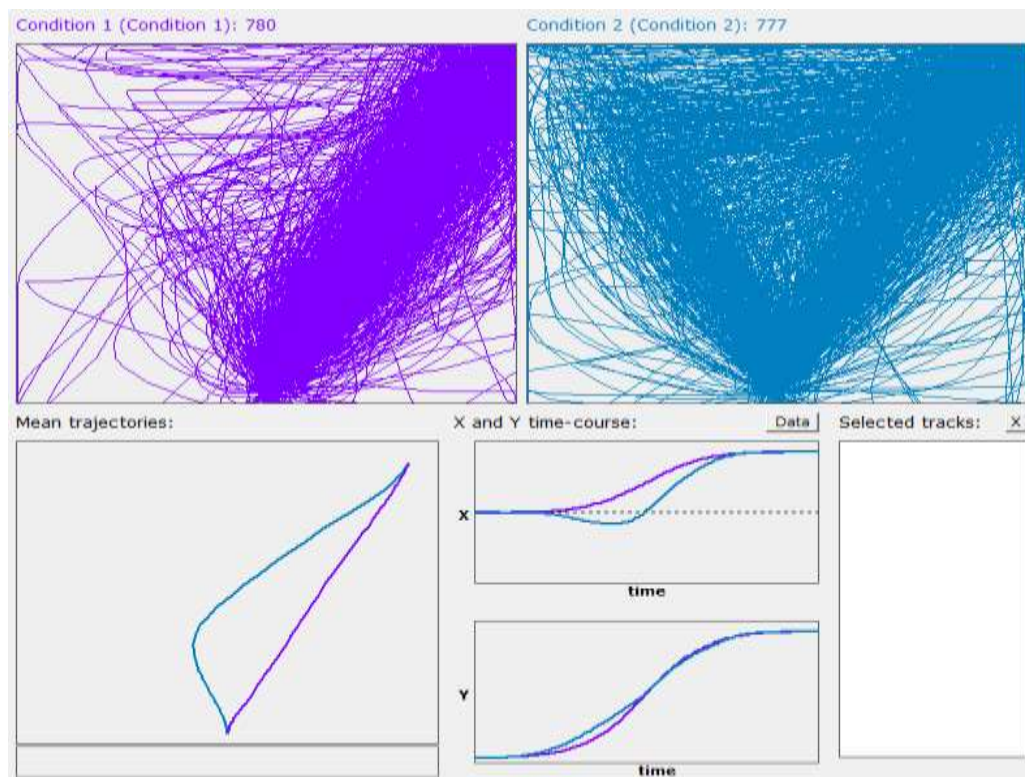


Figure 4.8 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper right in both condition 1 and condition 2.

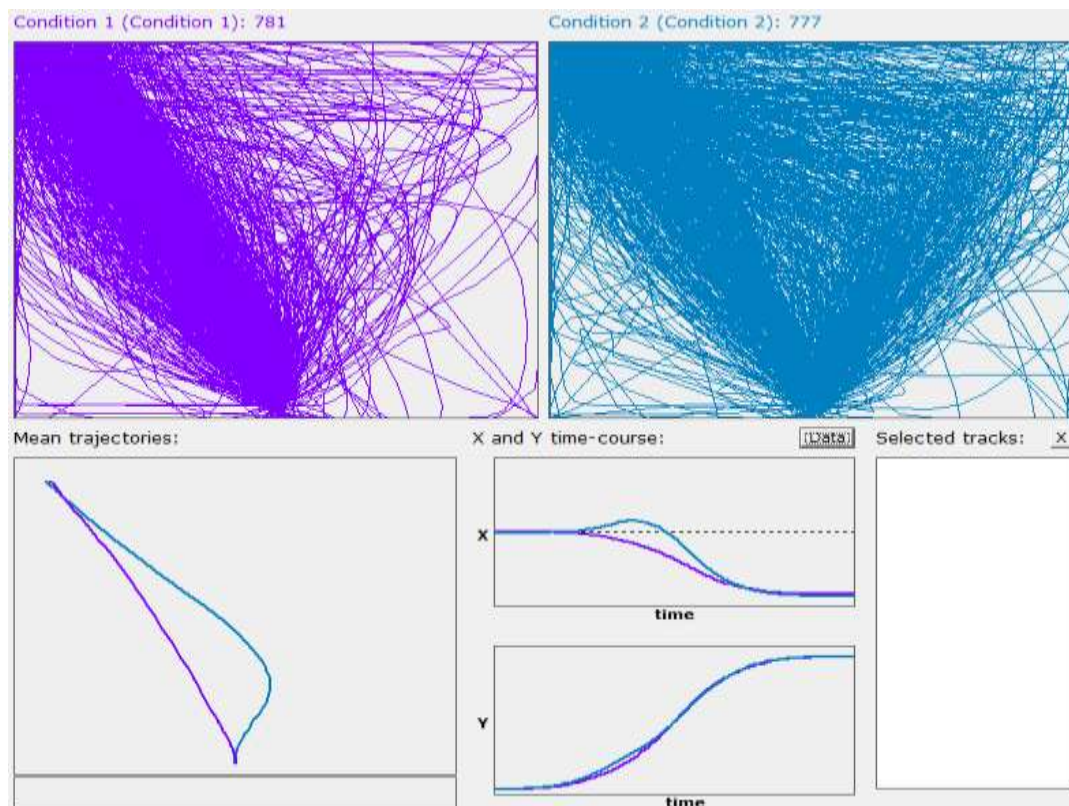


Figure 4.9 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper left in both compatible and conflict conditions.

## 4.2 The Results of Experiments 1 and 2

### 4.2.1 Reaction Time

The main goal of experiment 2 was to observe if similar response trajectories would be obtained if the participants responded to the same task by starting from the top center and clicking on the response boxes located on the left and right bottom corners. For that reason, the data obtained from Experiment 2 is analyzed together with the data from Experiment 1. A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the mean response times. The results revealed a significant main effect of condition,  $F(1, 102) = 109.87$ ,  $p < .001$ , partial  $\eta^2 = .52$  and a significant interaction of condition and location,  $F(1, 102) = 6.31$ ,  $p < .05$ , partial  $\eta^2 = .06$ .

The main effect of position,  $F(1, 102) = 2.82$ ,  $p > .05$ , the main effect of location,  $F(1, 102) = 1.59$ ,  $p > .05$ , the interaction of position and location,  $F(1, 102) = 0.02$ ,  $p > .05$ , the interaction of condition and position,  $F(1, 102) = 2.08$ ,  $p > .05$ , and the three way interaction,  $F(1, 102) = 3.00$ ,  $p > .05$  were not significant.

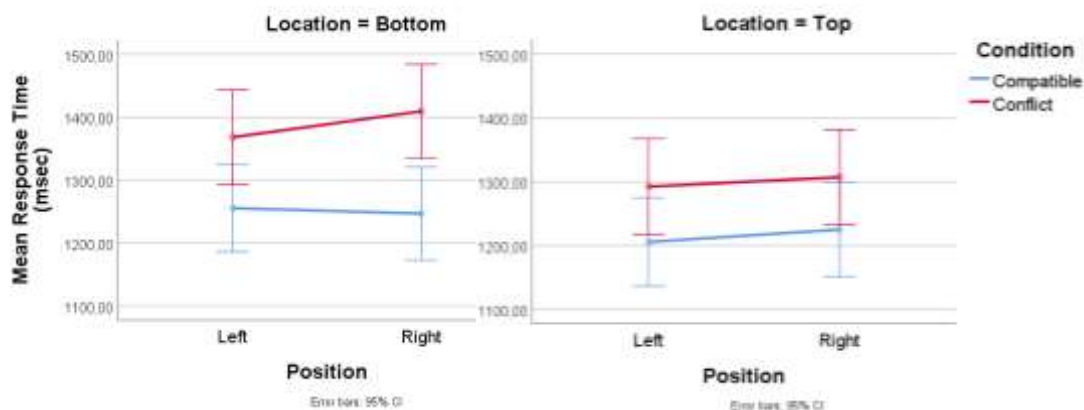


Figure 4.10 The line chart for average response times observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, these effects are further enhanced. In particular, the main effect of condition,  $F(1, 87) = 95.58$ ,  $p < .001$ , partial  $\eta^2 = .52$  and the interaction of condition and location,  $F(1, 87) = 7.38$ ,  $p < .01$ , partial  $\eta^2 = .08$  are still significant. Moreover, the interaction of condition and location,  $F(1, 87) = 4.51$ ,  $p < .05$ , partial  $\eta^2 = .05$  and the three-way interaction,  $F(1, 87) = 5.60$ ,  $p < .05$ , partial  $\eta^2 = .06$ , also reached significance when the sample is reduced to right-handed participants.

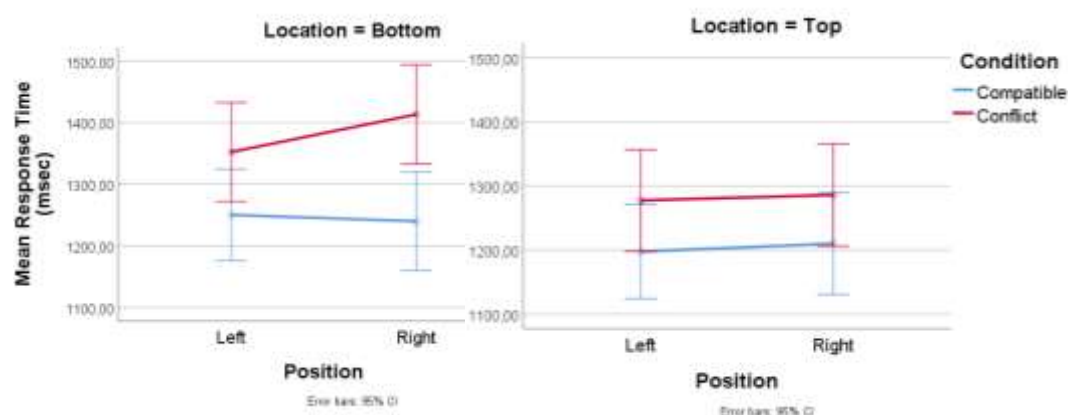


Figure 4.11 The line chart for average response times observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.



These results suggest that the participants experienced the expected Simon effect when the targets are presented at top or bottom, where they tended to respond slower in the conflict cases as compared to congruent cases. However, there is a disproportionate slowing down in the conflict case for the right position where the response buttons were placed in the bottom corners. This effect was further strengthened when the sample was reduced to right-handed participants.

#### 4.2.2 Maximum Deviation

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the mean maximum deviation. The results revealed a significant main effect of condition,  $F(1, 102) = 241.15$ ,  $p < .001$ , partial  $\eta^2 = .70$ , a significant main effect of position,  $F(1, 102) = 6.98$ ,  $p < .05$ , partial  $\eta^2 = .06$ , a significant interaction of condition and position,  $F(1, 102) = 12.04$ ,  $p < .01$ , partial  $\eta^2 = .11$ .

The main effect of location,  $F(1, 102) = 2.42$ ,  $p > .05$ , the interaction of condition and location,  $F(1, 102) = 2.90$ ,  $p > .05$ , the interaction of position and location,  $F(1, 102) = 2.28$ ,  $p > .05$ , and the three way interaction,  $F(1, 102) = .01$ ,  $p > .05$  were not significant.

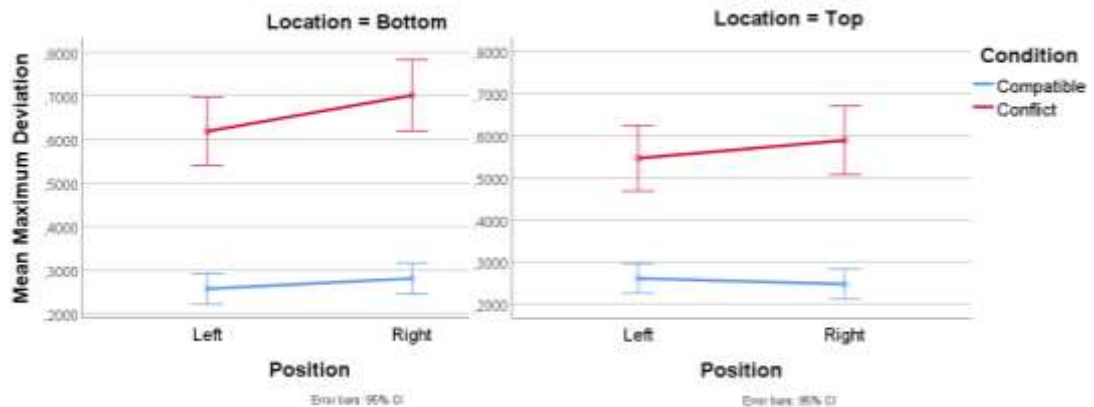


Figure 4.12 The line chart for average maximum deviation observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, these effects are further enhanced. In particular, the main effect of condition,  $F(1, 87) = 247.75$ ,  $p < .001$ , partial  $\eta^2 = .74$ , the main effect of position,  $F(1, 87) = 9.67$ ,  $p < .001$ , partial  $\eta^2 = .10$  and the interaction of condition and position,  $F(1, 87) = 11.68$ ,  $p < .01$ , partial  $\eta^2 = .12$  are still significant. Moreover, the interaction of condition and location,  $F(1,$

87)=4.16,  $p < .05$ , partial  $\eta^2 = .05$ , also reached significance when the sample is reduced to right-handed participants.

When we looked at the graphs, which are presented 4.12, the maximum deviation in the position "right" is higher in the conflict cases than in the compatible cases in the case when the response alternatives are on the bottom.

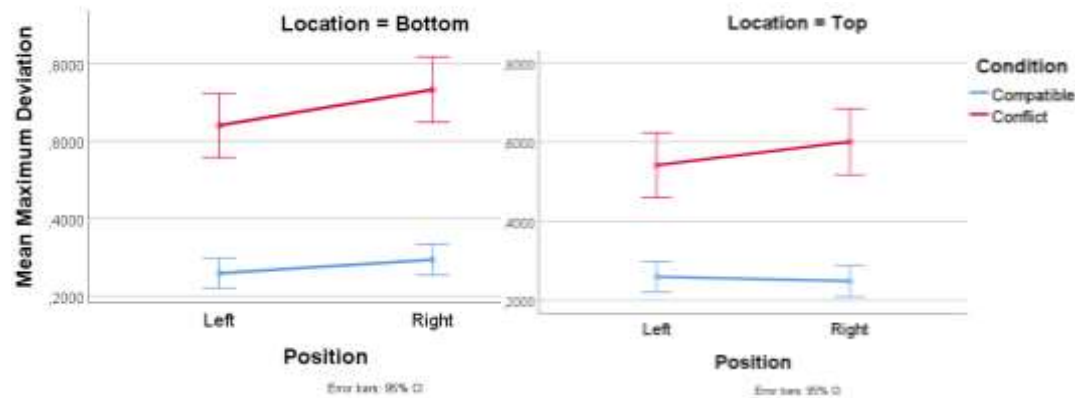


Figure 4.13 The line chart for average maximum deviation observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When we subtracted left-hand dominant participants from the data, the effect size slightly increased. Furthermore, the interaction of condition and location reached significance. This interaction effect tells us the maximum deviation on the compatible and conflict cases was different for top and bottom-placed response alternatives.

#### 4.2.3 MD Time

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the mean maximum deviation time. The results revealed a significant main effect of condition,  $F(1, 102) = 49.05$ ,  $p < .001$ , partial  $\eta^2 = .32$ .

The main effect of position,  $F(1,102)=3.35$ ,  $p > .05$  the main effect of location,  $F(1,102)=.83$ ,  $p > .05$ , the interaction of condition and location,  $F(1, 102) = .22$ ,  $p > .05$ , the interaction of position and location,  $F(1,102)=.00$ ,  $p > .05$ , the interaction of condition and position,  $F(1,102)=2.01$ ,  $p > .05$  and the three way interaction,  $F(1,102)=.96$ ,  $p > .05$  were not significant.

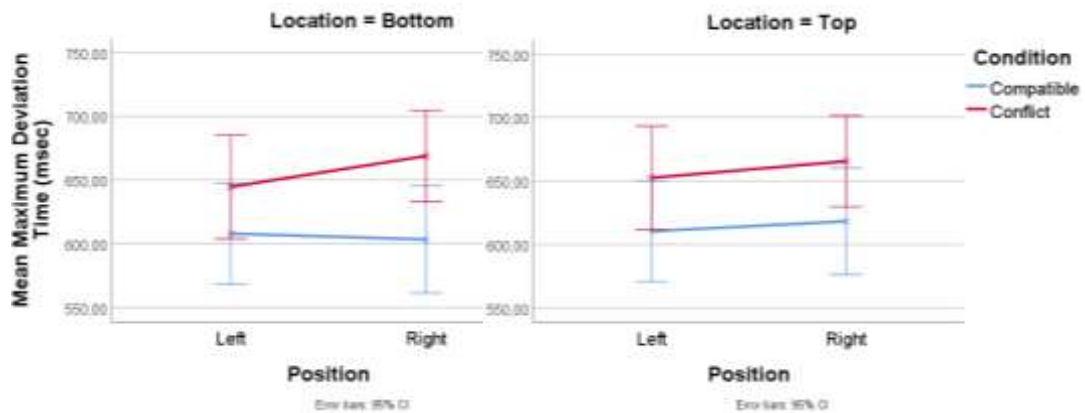


Figure 4.14 The line chart for average maximum deviation time observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When we looked at the graphs, which are presented 4.14, the maximum deviation time in the position "right" is higher in the conflict cases than in the compatible cases when the response alternatives are on the bottom. However, this effect is not significant ( $F(1,102)=3.35$ ,  $p>.05$ ). On the right graph in Figure 4.14, the lines are fairly parallel that tells us that regardless of the condition, there is a similar reduction in maximum deviation time on the position "left" and "right" when the response alternatives are on the top.

When the sample is restricted to right-hand dominant participants, these effects are further enhanced. In particular, the main effect of condition,  $F(1, 87) = 40.07$ ,  $p<.001$ , partial  $\eta^2 = .32$ , is still significant. Moreover, the interaction of condition and position,  $F(1, 87)=4.67$ ,  $p<.05$ , partial  $\eta^2 = .05$ , also reached significance when the sample is reduced to right-handed participants.

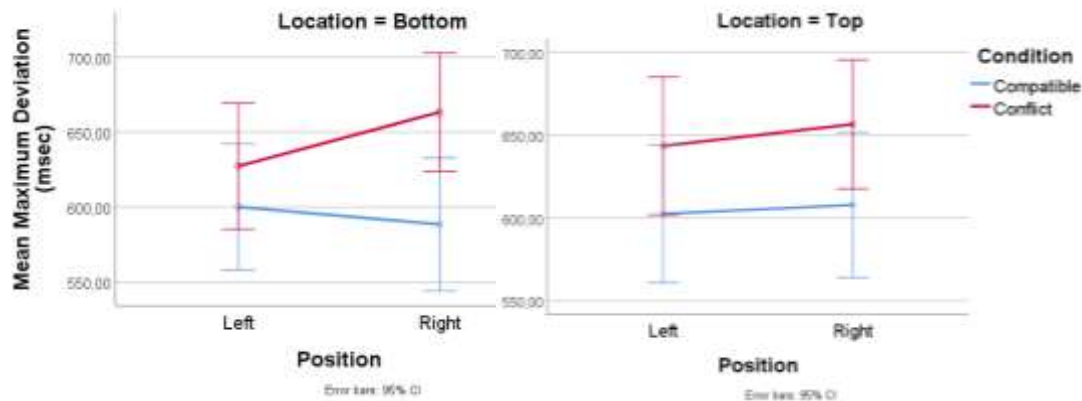


Figure 4.15 The line chart for average maximum deviation time observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When we subtracted left-hand dominant participants from the data the interaction of condition and position reached significance. When we look at the graphs presented in Figure 4.15 , it tells us the maximum deviation time on the “right” position was higher in the conflict cases than in the compatible cases.

#### 4.2.4 The Area under the Curve

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the area under the curve. The results revealed a significant main effect of condition,  $F(1, 102) = 180.87, p < .001$ , partial  $\eta^2 = .64$ , a significant main effect of position,  $F(1, 102) = 5.96, p < .05$ , partial  $\eta^2 = .06$ , a significant interaction of position and location,  $F(1, 102) = 10.79, p < .01$ , partial  $\eta^2 = .10$ , and a significant interaction of condition and position,  $F(1, 102) = 11.91, p < .01$ , partial  $\eta^2 = .10$ .

The main effect of location,  $F(1, 102) = 1.60, p > .05$ , the interaction of condition and location,  $F(1, 102) = 2.42, p > .05$ , and the three way interaction,  $F(1, 102) = 3.64, p > .05$  were not significant.

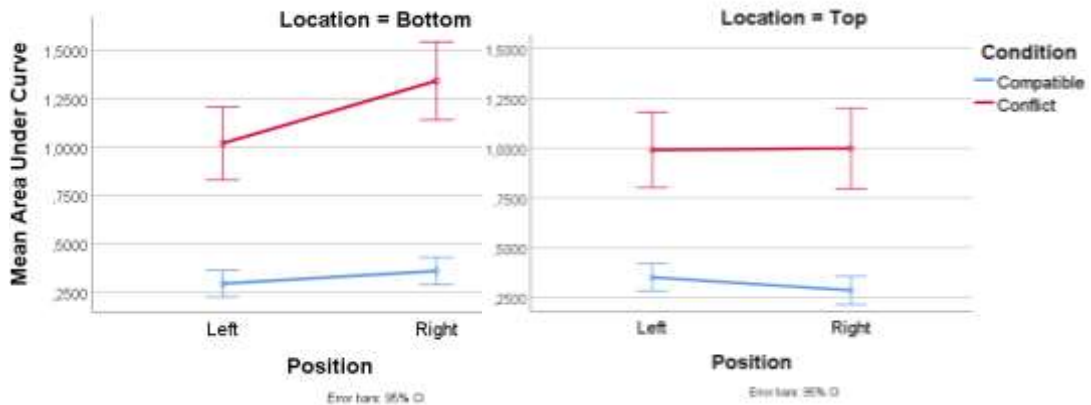


Figure 4.16 The line chart for average area under curve observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, these effects are slightly enhanced. In particular, the main effect of condition,  $F(1, 87) = 179.84$ ,  $p < .001$ , partial  $\eta^2 = .67$ , the main effect of position,  $F(1, 87) = 8.15$ ,  $p < .01$ , partial  $\eta^2 = .09$ , and the interaction of condition and position,  $F(1, 87) = 12.36$ ,  $p < .01$ , partial  $\eta^2 = .12$  is still significant. As for the interaction of position and location,  $F(1, 87) = 8.54$ ,  $p < .01$ , partial  $\eta^2 = .09$ , the effect size was slightly decreased.

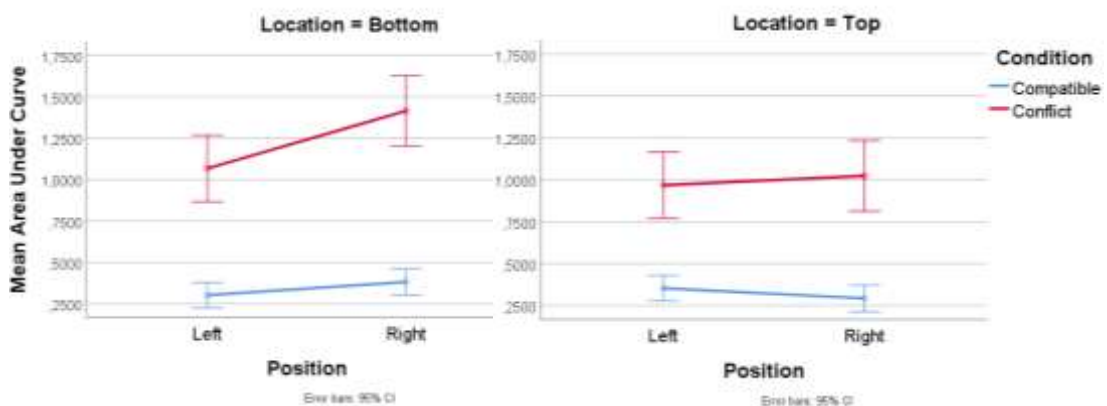


Figure 4.17 The line chart for average area under the curve observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

A significant interaction of position and location indicates that the area under the curve values of different positions (right vs. left) differed in bottom and top-placed response alternatives. Figure 4.16 reveals that, when the response alternatives on the bottom, mean of area under the curve values are higher in the position right than in the case where response alternatives are on the top. The lines in that situation is

much steeper for bottom location than it is for top location. When we subtracted the left-hand dominants from the data, its effect size is decreased, while it is still significant.

#### 4.2.5 X-Flip

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the x-flips. The results revealed a significant main effect of condition,  $F(1, 102) = 34.01$ ,  $p < .001$ , partial  $\eta^2 = .25$ , a significant main effect of position,  $F(1, 102) = 14.70$ ,  $p < .001$ , partial  $\eta^2 = .13$ , and a significant main effect of location,  $F(1, 102) = 39.97$ ,  $p < .001$ , partial  $\eta^2 = .28$ .

The interaction of condition and location,  $F(1, 102) = .07$ ,  $p > .05$ , the interaction of position and location,  $F(1, 102) = 1.86$ ,  $p > .05$ , the interaction of condition and position,  $F(1, 102) = .99$ ,  $p > .05$  and the three way interaction,  $F(1, 102) = .05$ ,  $p > .05$  were not significant.

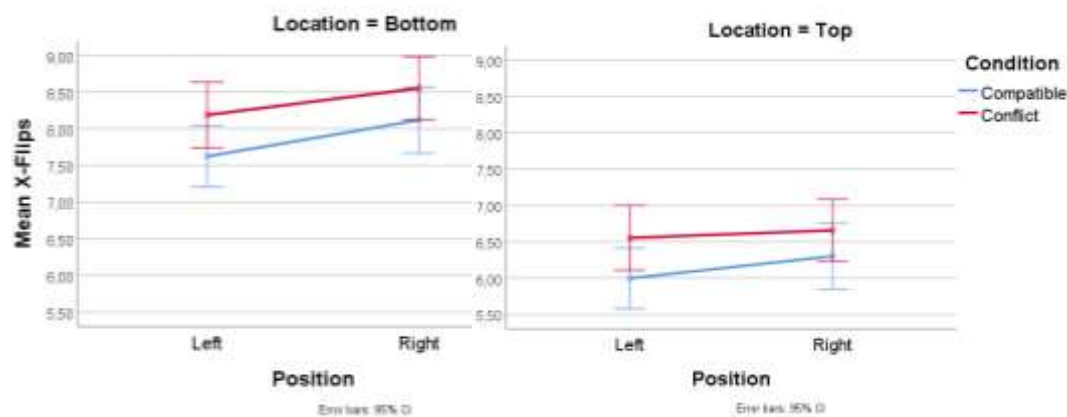


Figure 4.18 The line chart for average x-flips observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, these effects are further enhanced. In particular, main effect of condition,  $F(1, 87) = 29.93$ ,  $p < .001$ , partial  $\eta^2 = .26$ , a significant main effect of position,  $F(1, 87) = 19.78$ ,  $p < .001$ , partial  $\eta^2 = .18$ , and a significant main effect of location,  $F(1, 87) = 43.02$ ,  $p < .001$ , partial  $\eta^2 = .33$  is still significant.

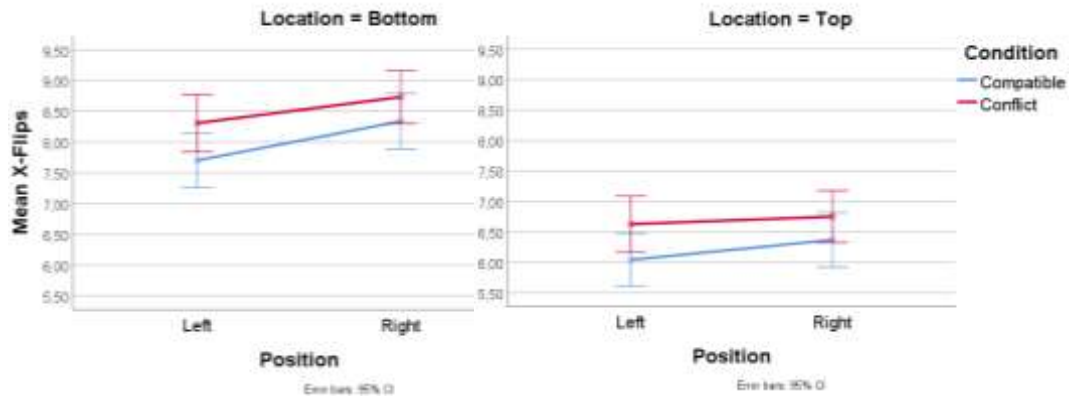


Figure 4.19 The line chart for average x-flips observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

The results indicate that the effect of location had a significant impact on the mean number of x-flips. The mean number of x-flips is higher in the case when the response alternatives are on the bottom than in the case where response alternatives located at the top. The lines are approximately parallel; that means regardless of conditions, there is a similar reduction on mean x-flips in positions.

#### 4.2.6 Y-Flips

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the y-flips. The results revealed a significant main effect of condition,  $F(1, 102) = 93.52$ ,  $p < .001$ , partial  $\eta^2 = .48$ , a significant main effect of position,  $F(1, 102) = 16.74$ ,  $p < .001$ , partial  $\eta^2 = .14$ , a significant main effect of location,  $F(1, 102) = 60.72$ ,  $p < .001$ , partial  $\eta^2 = .37$ , and a significant three way interaction,  $F(1, 102) = 5.87$ ,  $p < .05$ , partial  $\eta^2 = .05$ .

The interaction of condition and location,  $F(1, 102) = 2.45$ ,  $p > .05$ , the interaction of position and location,  $F(1, 102) = 1.07$ ,  $p > .05$  and the interaction of condition and position,  $F(1, 102) = .08$ ,  $p > .05$  were not significant.

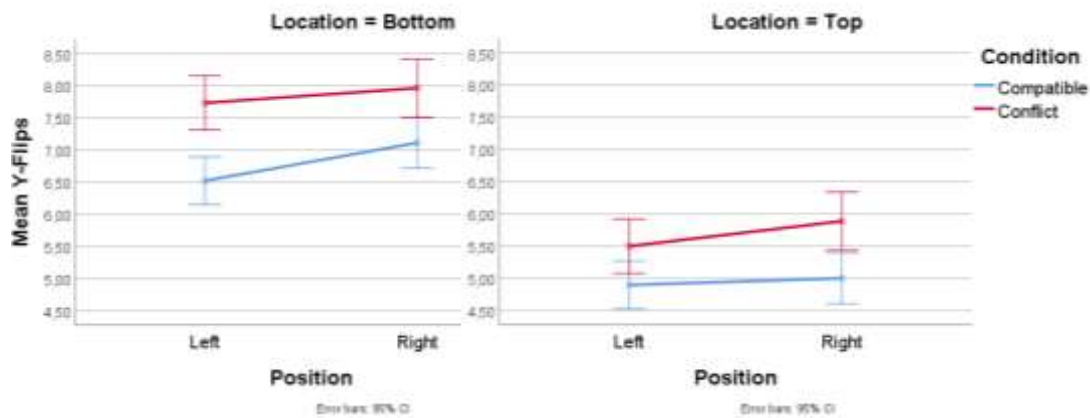


Figure 4.20 The line chart for average y-flips observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, main effect of condition,  $F(1, 87) = 80.22$ ,  $p < .001$ , partial  $\eta^2 = .48$ , a main effect of position,  $F(1, 87) = 15.47$ ,  $p < .001$ , partial  $\eta^2 = .15$ , a main effect of location,  $F(1, 87) = 70.68$ ,  $p < .001$ , partial  $\eta^2 = .45$  is still significant. However, a three way interaction,  $F(1, 87) = 3.02$ ,  $p > .05$ , partial  $\eta^2 = .03$ . was not significant anymore.

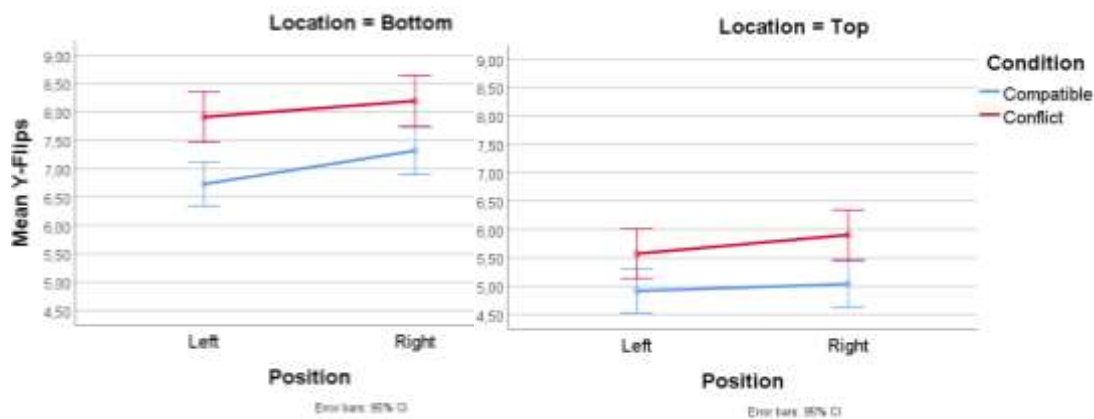


Figure 4.21 The line chart for average y-flips observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

The results indicate that the effect of location had a significant impact on the mean number of y-flips. The mean number of y-flips is higher in the case when the response alternatives are on the bottom than in the case where response alternatives located at the top.



#### 4.2.7 MD/AUC

A 2x2x2 mixed ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the target location (i.e. whether the clickable targets appear on the top or bottom corners) on the ratio of maximum deviation and the area under the curve. The results revealed a significant main effect of condition,  $F(1, 102) = 166.00$ ,  $p < .001$ , partial  $\eta^2 = .62$  and a significant interaction of position and location,  $F(1, 102) = 5.92$ ,  $p < .05$ , partial  $\eta^2 = .06$ .

The main effect of position,  $F(1, 102) = .14$ ,  $p > .05$ , the main effect of location,  $F(1, 102) = .56$ ,  $p > .05$ , the interaction of condition and location,  $F(1, 102) = 2.45$ ,  $p > .05$ , the interaction of condition and position,  $F(1, 102) = 1.18$ ,  $p > .05$ , and the three way interaction,  $F(1, 102) = .12$ ,  $p > .05$  were not significant.

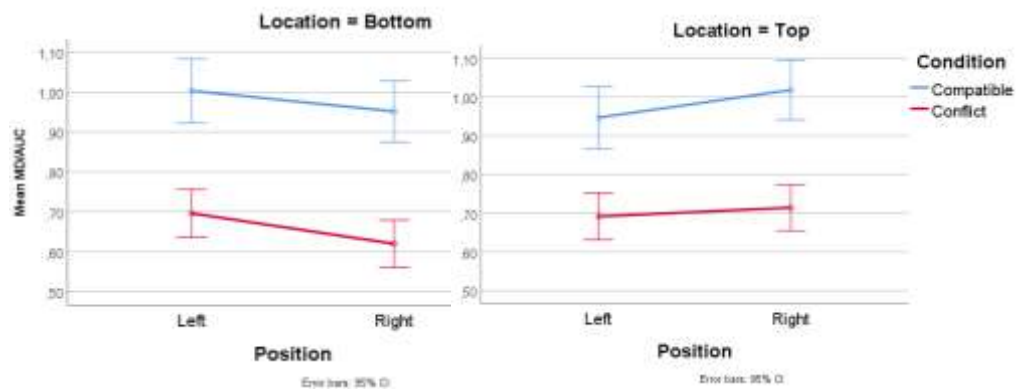


Figure 4.22 The line chart for average the ratio of maximum deviation and the area under the curve observed for compatible and conflict trials of all participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

When the sample is restricted to right-hand dominant participants, these effects are not changed. In particular, main effect of condition,  $F(1, 87) = 143.04$ ,  $p < .001$ , partial  $\eta^2 = .62$  and interaction of position and location,  $F(1, 102) = 5.97$ ,  $p < .05$ , partial  $\eta^2 = .06$ . is still significant.

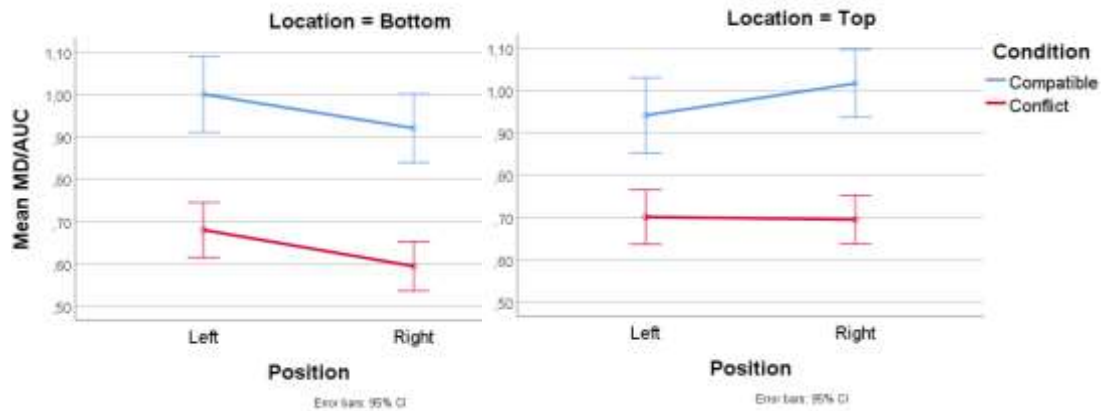


Figure 4.23 The line chart for average the ratio of maximum deviation and the area under the curve observed for compatible and conflict trials of right-handed participants for the left and right targets and when the response buttons were presented at the bottom and top corners of the screen.

#### 4.2.8 The Time Normalized Data

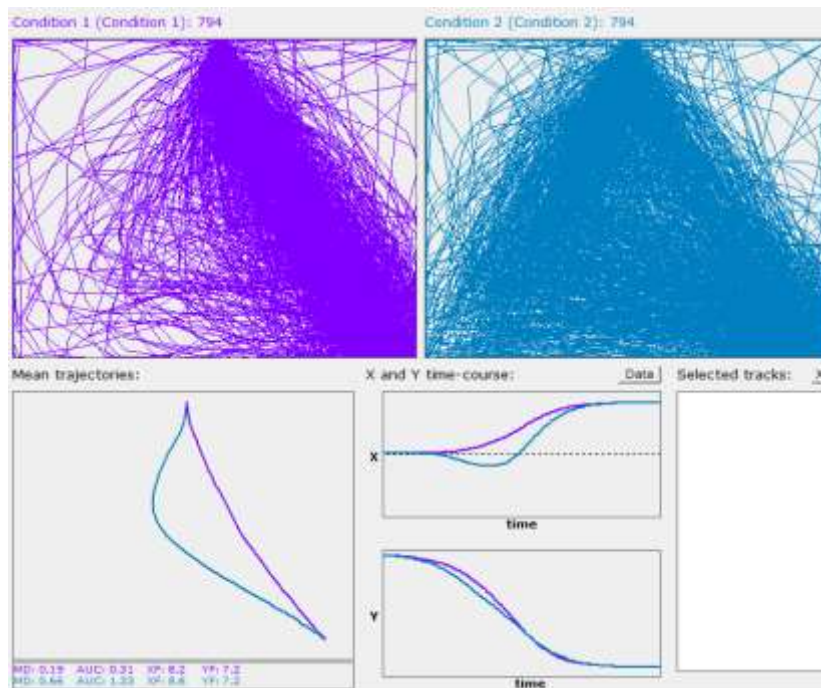


Figure 4.24 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the bottom right in both the compatible and conflict condition.

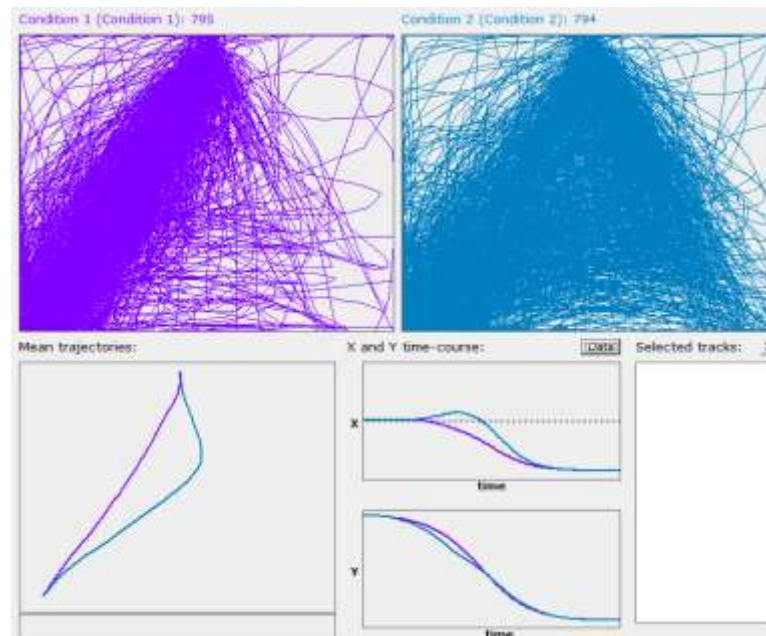


Figure 4.25 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the bottom left in both the compatible and conflict condition.

### 4.3 The Results of Experiment 3

#### 4.3.1 Reaction Time

Experiment 3 focused on the reverse Simon effect. During the first 32 trials the participants were exposed to trials with the color-location mapping where green is associated with left and red is associated with right. After the first stage, participants completed another set of 32 trials where the color-location mapping was reversed. Since the color-location mapping is rather arbitrary, in the analysis we focused on the last 16 trials of the first stage (to focus on the trials where the color-location association was reinforced), and the first 16 trials of the second stage (to focus on the region where the participants are adjusting to the new color-response mapping).

A 2x2x2 repeated measures ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the order (pre vs post) on the mean response times. The results revealed a significant main effect of condition,  $F(1, 71) = 17.12$ ,  $p < .001$ , partial  $\eta^2 = .19$ .

The main effect of order,  $F(1, 71) = .00$ ,  $p > .05$ , the main effect of position,  $F(1, 71) = .31$ ,  $p > .05$ , the interaction of order and condition,  $F(1, 71) = .01$ ,  $p > .05$ , the

interaction of order and position,  $F(1,71)=.21$ ,  $p>.05$ , the interaction of condition and position,  $F(1,71)=.88$ ,  $p>.05$  and the three way interaction,  $F(1,71)=.00$ ,  $p>.05$  were not significant.



Figure 4.26 The line chart for average response times observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively

When the sample is restricted to right-hand dominant participants, the results were not affected. The main effect of condition,  $F(1, 64) = 14.33$ ,  $p<.001$ , partial  $\eta^2 = .18$  is still significant. The main effect of order, the main effect of position and the interaction effects remained to be insignificant.

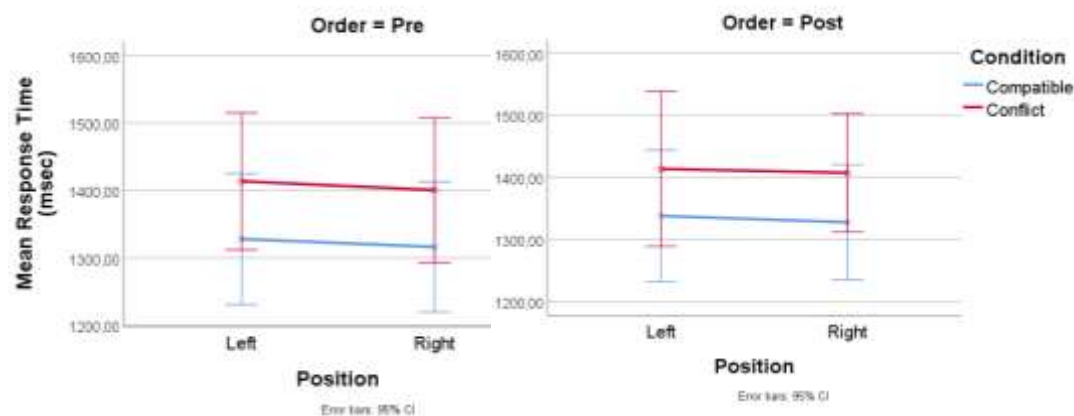


Figure 4.27 The line chart for average response time observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively

### 4.3.2 Maximum Deviation

A 2x2x2 repeated measures ANOVA was conducted to test the effect of response condition (compatible vs conflict), expected response position (left vs right), and the order (pre vs post) on the mean maximum deviation. Since the distribution of maximum deviation values were significantly right-skewed, a logarithmic transformation was first conducted. Since the resulting values satisfied the parametric assumptions, a 2x2x2 repeated measures ANOVA was conducted on the log-transformed maximum deviation values. The results revealed a significant main effect of condition,  $F(1, 71) = 225.48$ ,  $p < .001$ , partial  $\eta^2 = .76$  and a significant interaction of order and position,  $F(1,71)=4.42$ ,  $p < .05$ , partial  $\eta^2 = .06$ .

The main effect of order,  $F(1, 71) = 2.44$ ,  $p > .05$ , the main effect of position,  $F(1,71)=.86$ ,  $p > .05$ , the interaction of order and condition,  $F(1, 71) = .22$ ,  $p > .05$ , the interaction of condition and position,  $F(1,71)=.01$ ,  $p > .05$  and the three way interaction,  $F(1,71)=.17$ ,  $p > .05$  were not significant.

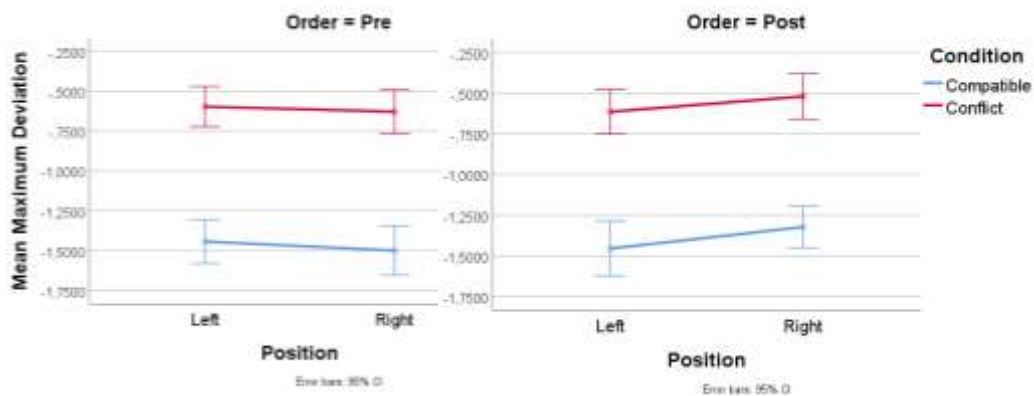


Figure 4.28 The line chart for average maximum deviation observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the main effect of condition,  $F(1, 64) = 187.57$ ,  $p < .001$ , partial  $\eta^2 = .75$  is still significant. However, interaction of order and position,  $F(1,64)=3.20$ ,  $p > .05$  is not significant anymore. The main effect of order, the main effect of position, the interaction of order and condition, the interaction of condition and position and the three-way interaction remained to be insignificant.

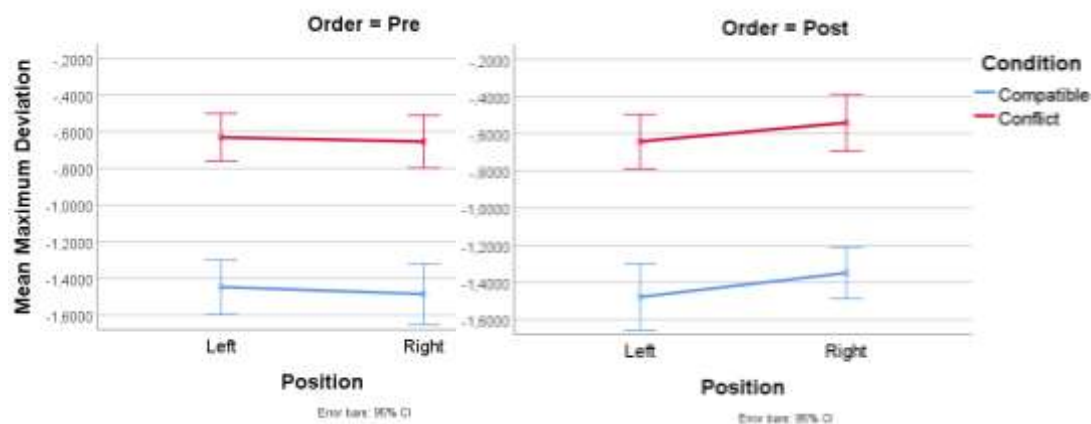


Figure 4.29 The line chart for average maximum deviation observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

A significant interaction of position and order indicates that the maximum deviation values of different positions (right vs. left) differed in pre and post experiments. Figure 4.28 reveals that in the post-experiment, mean of maximum deviation values are higher in the position right in both compatible and conflict conditions. When we subtracted the left-hand dominants from the data, the interaction effect has lost.

### 4.3.3 Maximum Deviation Time

Since the distribution of maximum deviation time values were significantly right-skewed, log-transformation was first conducted. A 2x2x2 repeated measures ANOVA was conducted on the log-transformed maximum deviation time values. The results revealed a significant main effect of condition,  $F(1, 71) = 154.93, p < .001$ , partial  $\eta^2 = .69$ .

The main effect of order,  $F(1, 71) = 3.64, p > .05$ , the main effect of position,  $F(1, 71) = .91, p > .05$ , the interaction of order and condition,  $F(1, 71) = .13, p > .05$ , the interaction of order and position,  $F(1, 71) = 2.30, p > .05$ , the interaction of condition and position,  $F(1, 71) = .59, p > .05$  and the three way interaction,  $F(1, 71) = 1.01, p > .05$  were not significant.



Figure 4.30 The line chart for average observed maximum deviation time for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the main effect of condition,  $F(1, 64) = 154.93$ ,  $p < .001$ , partial  $\eta^2 = .67$  is still significant. However, the effect size is slightly decreased. The main effect of order, the main effect of position and the interaction effects remained to be insignificant.

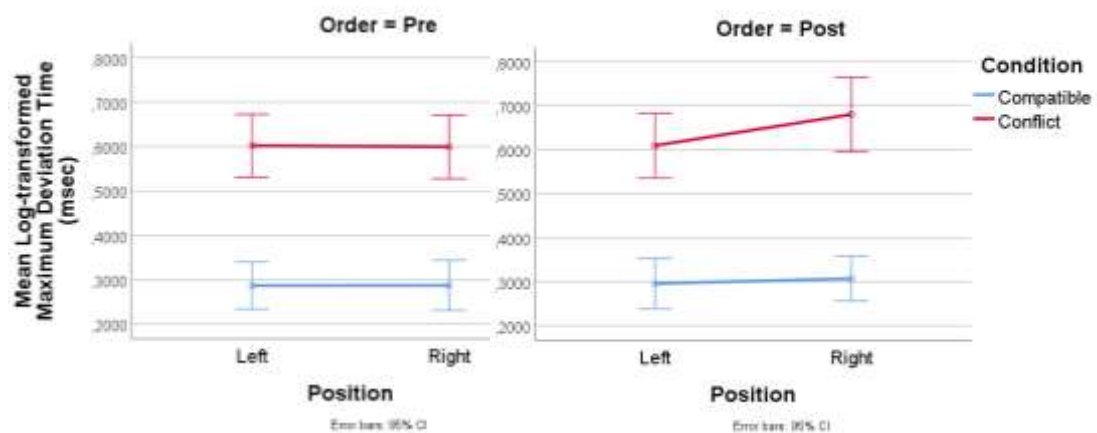


Figure 4.31 The line chart for average maximum deviation observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

#### 4.3.4 Area under the Curve

A 2x2x2 repeated measures ANOVA was conducted to test the effect of condition (compatible vs conflict), expected response position (left vs right), and the order (pre vs post) on the mean area under curve. Since the distribution of maximum deviation



values were significantly right-skewed, a logarithmic transformation was first conducted. Since the resulting values satisfied the parametric assumptions, a 2x2x2 repeated measures ANOVA was conducted on the log-transformed mean area under curve values. The results revealed a significant main effect of condition,  $F(1, 71) = 184.00$ ,  $p < .001$ , partial  $\eta^2 = .72$  and a significant interaction of order and position,  $F(1,71)=5.77$ ,  $p < .05$ , partial  $\eta^2 = .08$ .

The main effect of order,  $F(1, 71) = 1.14$ ,  $p > .05$ , the main effect of position,  $F(1,71)=2.52$ ,  $p > .05$ , the interaction of order and condition,  $F(1, 71) = .32$ ,  $p > .05$ , the interaction of condition and position,  $F(1,71)=.61$ ,  $p > .05$  and the three way interaction,  $F(1,71)=.13$ ,  $p > .05$  were not significant.

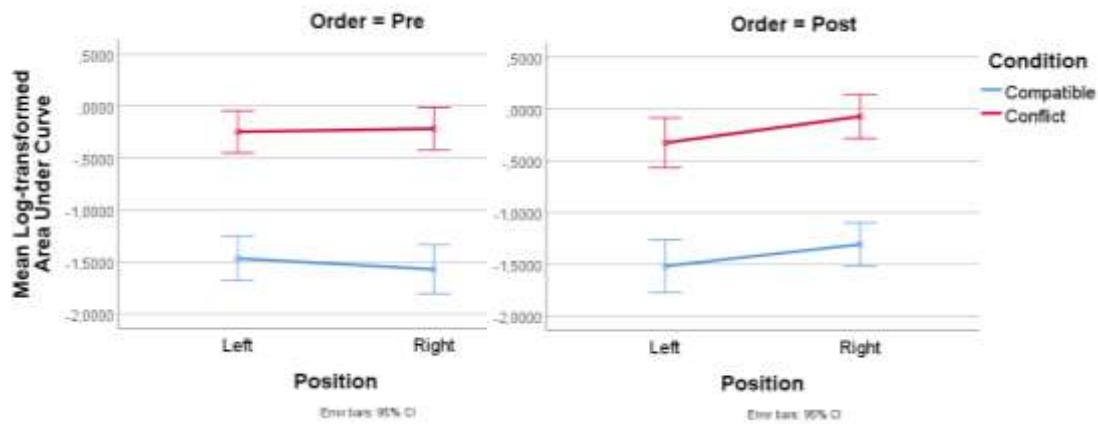


Figure 4.32 The line chart for average log-transformed area under curve observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the main effect of condition,  $F(1, 64) = 158.15$ ,  $p < .001$ , partial  $\eta^2 = .71$  and the interaction of order and position,  $F(1,64)=4.25$ ,  $p < .05$ , partial  $\eta^2 = .06$ . is still significant. The main effect of order, the main effect of position, the interaction of order and condition, the interaction of condition and position and the three-way interaction remained to be insignificant.



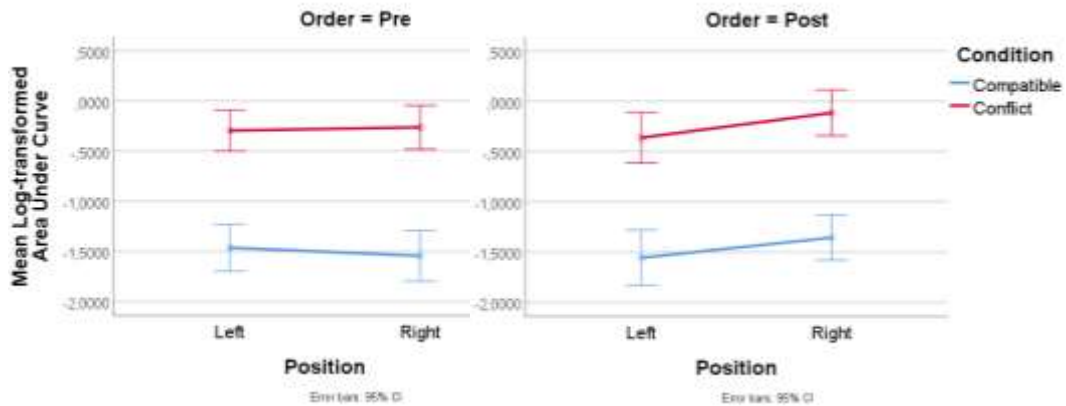


Figure 4.33 The line chart for average response time observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

A significant interaction of position and order indicates that the area under the curve values of different positions (right vs. left) differed in pre and post experiments. Figure 4.32 reveals that in the post-experiment, mean of area under the curve values are higher in the position right in both compatible and conflict conditions. When we subtracted the left-hand dominants from the data, the interaction effect is slightly decreased.

#### 4.3.5 X-Flips

A 2x2x2 repeated measures ANOVA was conducted to test the effect of condition (compatible vs conflict), expected response position (left vs right), and the order (pre vs post) on the mean x-flips. The results revealed a significant main effect of condition,  $F(1, 71) = 6.46, p < .05$ , partial  $\eta^2 = .08$ .

The main effect of order,  $F(1, 71) = 1.95, p > .05$ , the main effect of position,  $F(1, 71) = .42, p > .05$ , the interaction of order and condition,  $F(1, 71) = .01, p > .05$ , the interaction of order and position,  $F(1, 71) = .69, p > .05$ , the interaction of condition and position,  $F(1, 71) = .90, p > .05$  and the three way interaction,  $F(1, 71) = .00, p > .05$  were not significant.

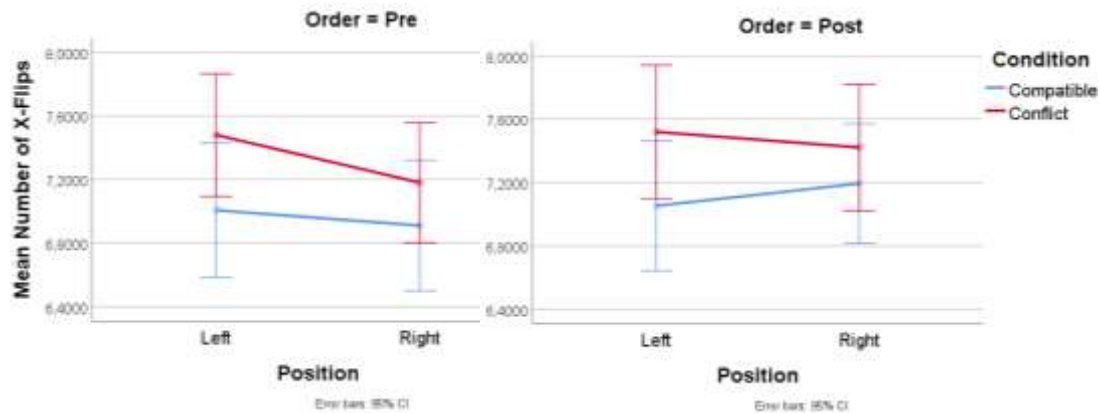


Figure 4.34 The line chart for average x-flips observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the results were not affected. The main effect of condition,  $F(1, 64) = 4.30, p < .05$ , partial  $\eta^2 = .06$  is still significant. The main effect of order, the main effect of position and the interaction effects remained to be insignificant.

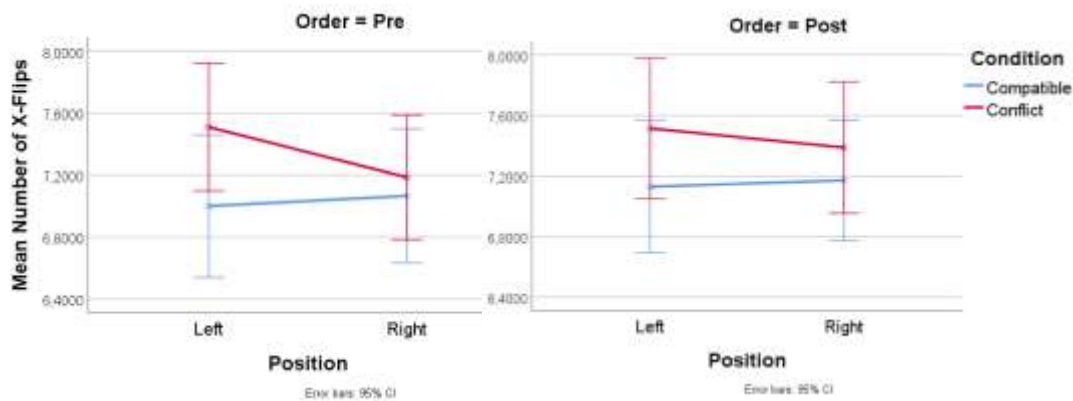


Figure 4.35 The line chart for average x-flips observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

### 4.3.6 Y-Flips

A 2x2x2 repeated measures ANOVA was conducted to test the effect of condition (compatible vs conflict), expected response position (left vs right), and the order (pre vs post) on the y-flips. The results revealed a significant main effect of condition,

$F(1, 71) = 15.71, p < .001$ , partial  $\eta^2 = .18$ , and a significant interaction of order and position  $F(1, 71) = 16.87, p < .001$ , partial  $\eta^2 = .19$

The main effect of order,  $F(1, 71) = .01, p > .05$ , the main effect of position,  $F(1, 71) = .39, p > .05$ , the interaction of order and condition,  $F(1, 71) = .71, p > .05$ , the interaction of condition and position,  $F(1, 71) = .05, p > .05$  and the three way interaction,  $F(1, 71) = .05, p > .05$  were not significant.

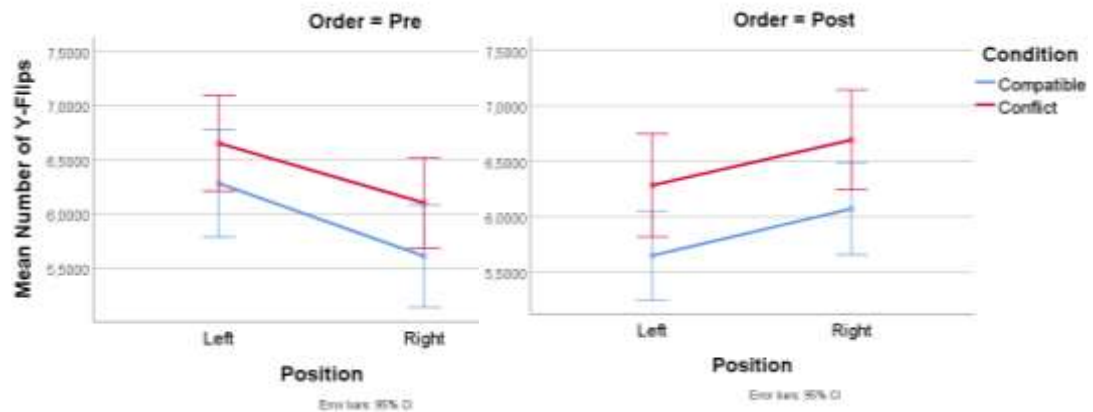


Figure 4.36 The line chart for average y-flips observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the main effect of condition,  $F(1, 64) = 9.88, p < .01$ , partial  $\eta^2 = .13$  and the interaction effect of order and position  $F(1, 64) = 13.07, p < .01$ , partial  $\eta^2 = .17$  is still significant, while their effect-sizes decreased. The main effect of order, the main effect of position, the interaction of order and condition, the interaction of condition and position and the three-way interaction remained to be insignificant.

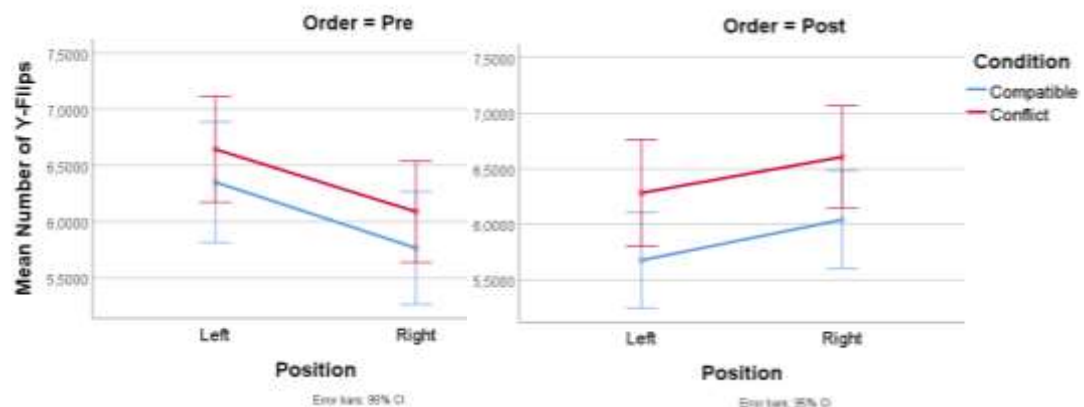


Figure 4.37 The line chart for average y-flips observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

A significant interaction of position and order indicates that the mean number of y-flips values of different positions (right vs. left) differed in pre and post experiments. Figure 4.36 reveals that in the post-experiment, mean of number of y-flips values are higher in the position right in both compatible and conflict conditions than the pre-experiment. However, in the pre-experiment mean number of y-flips values are higher in the position left in both compatible and conflict conditions than the post-experiment. We subtracted the left-hand dominants from the data, the interaction effect is slightly decreased.

#### 4.3.7 MD/AUC

Since the distribution of the ratio of the maximum deviation and area under the curve values were significantly right-skewed, log-transformation was first conducted. A 2x2x2 repeated measures ANOVA was conducted on the log-transformed values. The results revealed a significant main effect of condition,  $F(1, 71) = 97.77$ ,  $p < .001$ , partial  $\eta^2 = .58$ , a significant main effect of position,  $F(1, 71) = 4.14$ ,  $p < .05$ , partial  $\eta^2 = .06$ , and significant interaction of order and position,  $F(1, 71) = .55$ ,  $p < .05$ , partial  $\eta^2 = .07$ .

The main effect of order,  $F(1, 71) = .03$ ,  $p > .05$ , the interaction of order and condition,  $F(1, 71) = .01$ ,  $p > .05$ , the interaction of order and position,  $F(1, 71) = .40$ ,  $p > .05$ , the interaction of condition and position,  $F(1, 71) = 2.82$ ,  $p > .05$  and the three way interaction,  $F(1, 71) = .06$ ,  $p > .05$  were not significant.

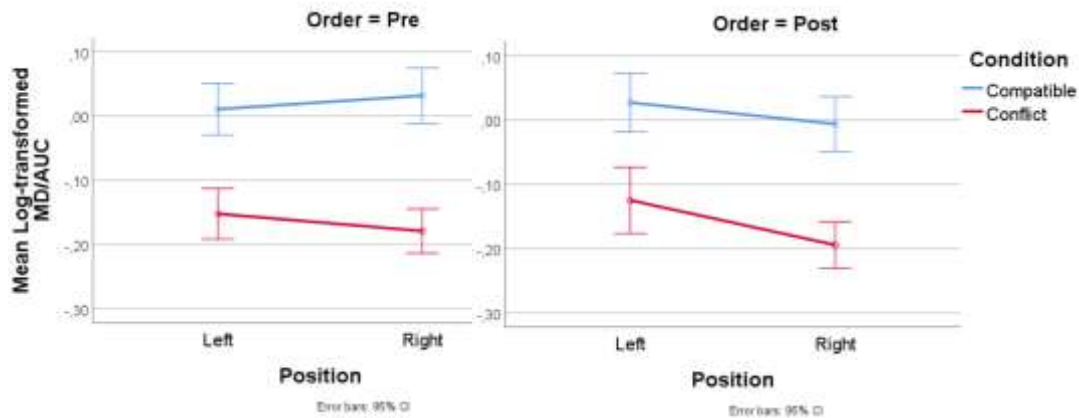


Figure 4.38 The line chart for average ratio of the maximum deviation and area under the curve values observed for compatible and conflict trials of all participants for the left and right targets in the pre and post experiments, respectively.

When the sample is restricted to right-hand dominant participants, the main effect of condition,  $F(1, 64) = 86.42$ ,  $p < .001$ , partial  $\eta^2 = .58$  and the interaction effect of

order and position  $F(1, 64) = 4.14$ ,  $p < .05$ , partial  $\eta^2 = .06$  remained significant. However, The main effect of position,  $F(1,64)=3.14$ ,  $p > .05$  became insignificant. The main effect of order, the interaction of order and condition, the interaction of order and position, the interaction of condition and position, and the three way interaction remained to be insignificant.

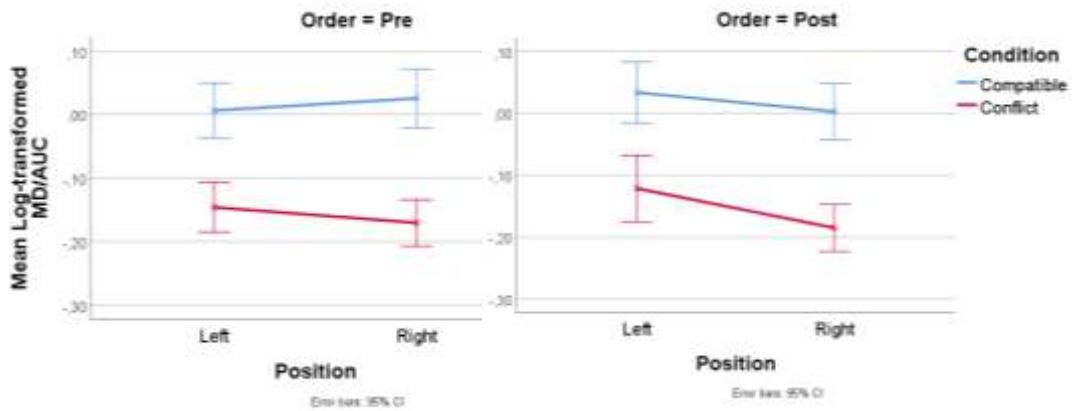


Figure 4.39 The line chart for average ratio of the maximum deviation and area under the curve values observed for compatible and conflict trials of right-handed participants for the left and right targets in the pre and post experiments, respectively.

### 4.3.8 The Normalized Time Data

The time normalized data in the first part of the third experiment is shown in the Figure 4.40. and 4.41. In the figure 4.40, the plot of trajectories which collected from the third experiment's data in compatible and conflict conditions can be seen. In particular, here the compatible condition is green box in which is the middle-left of the screen and the conflict condition is green box in which is the middle-right of the screen. In this pre-part of the experiment, the green box was shown on the top left of the screen, while the red box was shown on the top right of the screen.

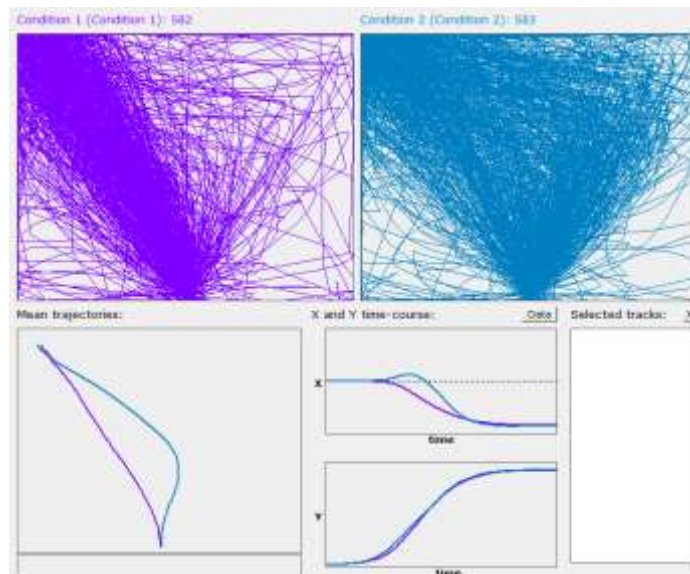


Figure 4.40 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper left in both condition 1 and condition 2.

In the Figure 4.40., we can see the plot of trajectories which collected from the third experiment's data in compatible and conflict conditions can be seen. In particular, here the compatible condition is red box in which is the middle-right of the screen and the conflict condition is red box in which is the middle-left of the screen.

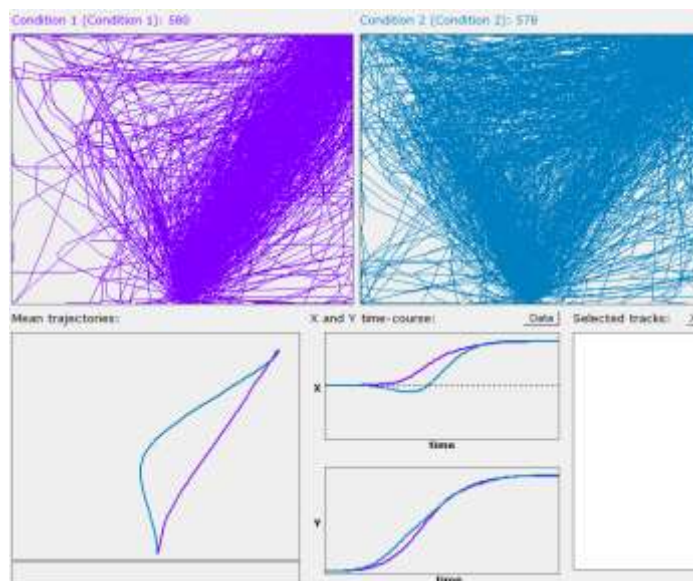


Figure 4.41 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper right in both condition 1 and condition 2.

The time normalized data in the second part of the third experiment is shown in the Figure 4.42. and 4.43 In the figure 4.42, the plot of trajectories which collected from the third experiment's data in compatible and conflict conditions can be seen. In particular, here the compatible condition is green box in which is the middle-right of the screen and the conflict condition is green box in which is the middle-left of the screen. In this post-part of the experiment, the green box was shown on the top right of the screen, while the red box was shown on the top left of the screen.

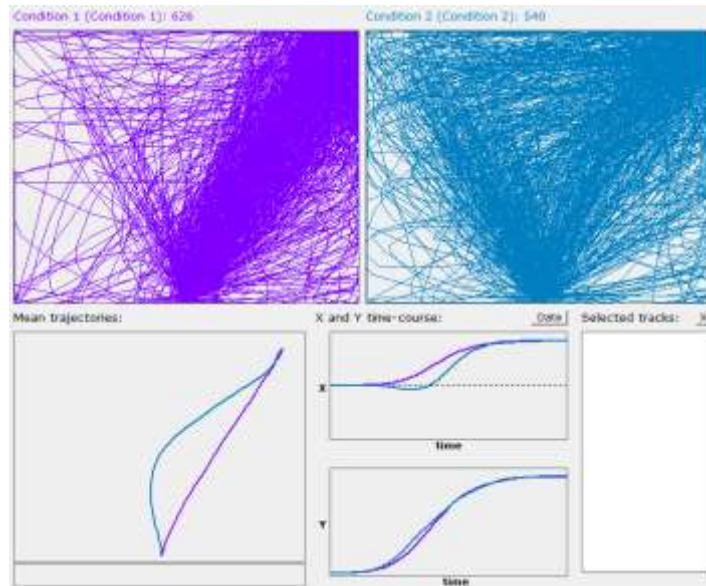


Figure 4.42 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper right in both condition 1 and condition 2.

Lastly, In the figure 4.43, the plot of trajectories which collected from the third experiment's data in compatible and conflict conditions can be seen. In particular, here the compatible condition is red box in which is the middle-left of the screen and the conflict condition is red box in which is the middle-right of the screen.



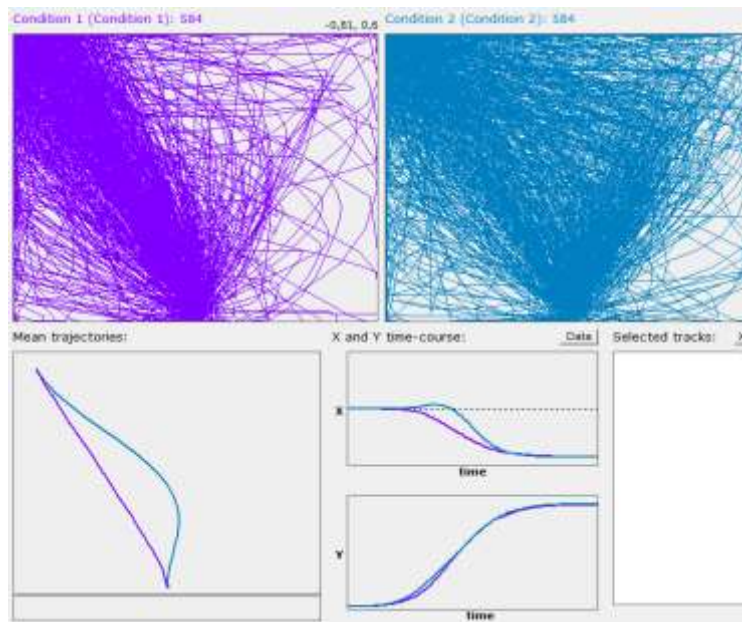


Figure 4.43 The plot of trajectories which is time-normalized for every single trial in compatible (condition 1) and conflict (condition 2) conditions. The plot reflects only the trajectories which ended in the upper left in both condition 1 and condition 2.



## CHAPTER 5

### DISCUSSION AND CONCLUSION

In this chapter, the results of the experiments are discussed and summarized. Afterwards, a discussion on the limitations of the study and pointers for future work are provided.

#### 5.1 Discussion

In the present study, we replicated the well-known Simon and the reverse Simon effects in a mouse-tracking paradigm to explore what additional insights can be obtained from monitoring hand dynamics in a stimulus-response compatibility setting. We also investigated the impact of experiment design factors on mouse-tracking data. Three experiments were conducted to investigate these effects. As expected, the mouse tracker experiments showed a significant stimulus-response compatibility effect as evidenced in mean response time comparisons among conflict and congruent trials, where participants were significantly faster in responding to cases where the instruction and its location were compatible with each other. Among the measurements obtained, AUC (partial  $\eta^2 = .68$ ), MD (partial  $\eta^2 = .61$ ) and the composite indicator MD/AUC (partial  $\eta^2 = .55$ ) had higher effect sizes as compared to response time (partial  $\eta^2 = .49$ ), which suggests that features associated with mouse dynamics can provide stronger indicators for the response-compatibility effect.

What is immediately not visible to the response time analysis is concerned with the dynamic complexity of the mouse trajectories that took shape in each trial. In the first experiment, the interaction effect observed for the MD measures suggest that the participants were significantly more hesitant to click on the right button (partial  $\eta^2 = .08$ ) when the stimulus “Right” was not in alignment with the response towards the right, as compared to the left button, whereas no such distinction between left and right directions was observed in congruent trials. Finally the significantly higher mean y-flips (partial  $\eta^2 = .11$ ) showed observed in the right responses suggest that the participants exhibited more complex trajectories when they were supposed to click on the right button in the conflict trials. Although rather small in effect size, the asymmetry between left and right responses during conflict trials is slightly strengthened when the sample is restricted to right-handed subjects. This suggests that the response directions towards the left and right corners are not entirely

symmetric in the conflict cases, which may be due to the fact that the computer users are accustomed to drag the mouse to top left corner as they begin to browse their computers' screens while reading electronic documents and surfing the web etc. Such saddle differences could not be detected by response time analysis only, and they need to be carefully considered if the expected effect size for discriminating choices are also rather low as these factors may confound the results.

In an effort to test whether using the top corners to elicit responses could differ from a response mapping using the bottom corners, we ran a follow up study by implementing a reversed setup with a top-to-bottom response trajectory condition, and contrasted the observed mouse measures with those obtained from the first experiment. The results indicate that there is a significant difference between the conflict and the compatible conditions on RT, MD, MD-Time, AUC, x-flips, and y-flips. Thus, the participants experienced the expected Simon effect when the targets are presented at the top or bottom. When we compared the collected data of the first and second experiments, we found a disproportionate slowing down in the conflict case for the right position where the response buttons were placed in the bottom corners in terms of reaction time. Moreover, when the target was "right," the maximum deviation value is higher in the conflict cases than in the compatible cases in the case when the response alternatives are on the bottom. When we restricted the sample to right-hand dominant participants, the interaction of condition and location reached significance, which means the maximum deviation on the compatible and conflict cases were different for top and bottom-placed response alternatives. In other words, switching the response mapping to top-to-bottom have increased the asymmetry between left and right cases during conflict trials. In the top-to-bottom setup the participants slowed down slightly, which reached significance only if the sample is reduced to right-hand dominant people.

The results of experiments 1 and 2 corroborate with the findings that mouse movements are influenced by the differences in the setup of mouse tracking experiments (Scherbaum & Kieslich, 2018). In particular, we found that the right and left responses may not follow symmetric trajectories, especially in conflict cases. Such saddle differences may need to be addressed during experimental design by increasing the number of decision trials and counterbalancing the response locations. Web usability should be taken into account as well; in particular, the tendency to click on the menus where located left-hand side due to its influence in the way mouse is used during computer use.

Finally, in experiment 3 we investigated the reversal of the Simon effect by first associating red and green colors to specific response directions through repeated trials, and then switching the mapping to reinforce the other way around. We checked which indicators would be the most sensitive to the dynamical changes due to the transition. We again observed a significant difference in RT between conflict and congruent cases, but the effect size was dropped to .19, and no interaction between pre- and post-switch averages. MD and AUC contrasts provided much larger effect sizes for the main effect of congruent and conflict trials, but their

interaction with pre- and post-mapping change was only marginally significant. The reversal effect was most vivid in the case of y-flips, which seemed to be the best indicator for the process of adjusting to the new color-response pairing.

## **5.2 Conclusion**

Overall, the three experiments conducted in the scope of this thesis suggest that mouse tracking is a viable methodology to probe into the dynamics of decision-making processes in conflicting and non-conflicting cases. The measures that quantify the complexity of the mouse trajectories while responding to decisions with strong and weak attractors turned out to be useful to better account for the differences between decisions that involve the resolution of a conflict. Mouse tracking provides a wealth of indicators to quantify the differences between experimental conditions that were not possible with classical response time analysis.

The results of the study can also be considered within the frame of the perception-action coupling paradigm. James Gibson's words can recapitulate this paradigm: "We must perceive in order to move, but we must also move in order to perceive" (Gibson, 1979; Warren, 1990, p.23). In this way, the participants tend to make their first move, and then they decide on their way of a move to guide their movements. Although there is no feedback mechanism, mouse movements were updated by the participants' mouse movements. Planning and execution process are not separated, because of the mouse movements are considered as dynamical evolving process.

## **5.3 Limitations and Future Directions**

In this study the sequential dependencies among the trials were not analyzed. This could be particularly useful to document the transition from one stimulus-response mapping into the opposite mapping to better show the dynamics of that transition. Several other parameters such as the mouse cursor speed, velocity changes and response box dimensions were not systematically varied. A follow up study including a design where the responses are located on the left-top and left-bottom corners could be investigated to check whether the asymmetry among choice locations are reduced or not. Moving the mouse to see the mouse cursor at the very beginning of the experiments can be another factor that results in the asymmetry of the results of the study. Although Mouse tracker software has some precautions such as recording the mouse movements after the participants click on the "start" button, this factor can conceive the discontinuity effect at some of the trials. Another follow up experiment can be conducted to compare how the starting conditions affect the results of the experiments with the help of the MouseTracker Software's experimental parameters.

Another factor for understanding the perception-action interaction is a lateralization effect (Nishimura and Yokosawa, 2009). Although the mouse tracker experiments conducted in this thesis showed a significant stimulus-response compatibility effect, to eliminate the lateralization effect caused by left-handedness, we excluded left-hand dominants participants from the data. Another study can be conducted to understand the differences underlying these lateralization effects by the help of MouseTracker Softwares' measures such as RT, MD, MD-Time, AUC, x-flips, and y-flips. Laterality and collected measures also can be used as a parameter in the Planning Domain Definition Language (PDDL) which regulates movement according to stimulus type for Simon Task in the scope of planning-action paradigm. The collected measures can also be used to investigate the human-computer interaction area with the Fitts Law and the Power Law of Practice, and the same design could be combined with the eye tracker experiment in order to get insight into the cognitive process.

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