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Investigation of Response Dynamics in the Simon Task with Mouse Tracking Methodology

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ABSTRACT

Introduction: Despite their popularity in Neuropsychology, reaction time analysis based on the subtraction and additive factors methods is critiqued for not paying adequate attention to the dynamical nature of cognition. Mouse-tracking methods aim to cater to this need by allowing researchers to explore response dynamics during cognitive tasks by recording mouse trajectories.

Methods: A mouse-tracking adaptation of the Simon task is developed to explore decision-making dynamics in different stimulus-response compatibility conditions. The study focuses on the effects of stimulus design decisions on mouse trajectories, including relocation of the choice buttons from the top corners to the bottom and the mid-session reversal of stimulus-response mapping on mouse responses.

Results: Consistent with previous studies, significant stimulus-response compatibility effects were observed, where contrasts over mouse-tracking measures had larger effect sizes than simple reaction time contrasts. Moreover, in the conflict trials, asymmetric response trajectories towards the left and right corners were observed. Moving the response buttons from top to bottom increased the degree of asymmetry between the mouse trajectories towards the bottom-left and bottom-right corners during the conflict condition. Finally, in the reverse Simon task, the switch to a new color-response mapping inflicted the largest effect on the average number of y-flips.

Conclusion: Mouse tracking provides measures suitable for exploring decision-making dynamics beyond classical reaction time analysis, provided asymmetries due to the starting position and response layout are considered during experiment design.

Keywords: Stimulus-response compatibility, Simon effect, mouse tracking, response dynamics

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INTRODUCTION

In neuropsychology, investigating the nature of mental processing has been a primary concern, and reaction time analysis is a commonly employed approach for this purpose (1). Since Donders proposed the *subtraction method* (2), experiments that build on each other are popularly employed to investigate the time course of various kinds of mental processes. This approach typically involved experiments where participants are exposed to conditions that differ only in the mental stage of interest. For example, Donders (2) proposed the comparative use of reaction times observed during a simple task (e.g., press the button when a stimulus appears), a go/no-go task (e.g., press the button if the target appears among the choices) and a choice task (e.g., if option 1/2 is seen, then press left/right) to estimate the duration of *stimulus discrimination* by subtracting the average completion times of the second task from the first task, and *response choice* by subtracting the third task from the second.

Despite the methodological rigor provided by this approach, the way participants adjust their responses during an experiment due to *learning* effects, and the *speed-accuracy tradeoff* presents challenges to the subtraction analysis (3). Such adaptations make it difficult to probe into the targeted cognitive process through direct comparison of different tasks. The *additive factors* approach (4) aims to remedy such issues by using different variants of the same task for a subtraction analysis instead of comparing different but complementary tasks. This approach also makes some critical assumptions, such as (a) the time cost of responses such as pressing a button takes the same amount of time irrespective of the differences in the complexity of the processed information across tasks, (b) the total response time is the sum of the time-cost of the related sub-processes, and (c) the time costs of subprocesses can be estimated by dividing the time cost of a larger but measurable process (4).

Approaches based on Signal Detection Theory (5) aim to address some of these shortcomings by probabilistic analysis of hits (stimulus correctly matched response irrespective of its location) and false alarms (the irrelevant stimulus location led to an incorrect response). In this approach, by choosing a time window forcing a speed-accuracy tradeoff, the competition among the processing of task-relevant attribute (e.g., color, shape) and the task-irrelevant spatial position of the stimulus, which may or may not match the correct response location, is amplified. This setup allows the estimation of parameters that can characterize signal detection thresholds and predict responses by adding typically Gaussian noise to the signal. However, while participants are engaged with a complex cognitive process such as decision making, distinguishing the motor response from the resolution of a conflict can be challenging since conflict resolution may occur during a response in a non-additive

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fashion (6). Such issues have motivated methodological approaches that can more effectively unravel the dynamical unfolding of these processes (7, 8).

Mouse tracking has recently emerged as a practical methodology to cater to the need for tracking response dynamics in neuropsychological studies. Software tools such as the MouseTracker (9) and MouseTrap (10) enable continuous tracking of mouse movements during various cognitive tasks. A standard mouse-tracking experiment layout for a two-choice decision task typically consists of a stimulus displayed in the middle of the screen and the two choices located in the upper left and right corners. In each trial, participants are supposed to move the mouse cursor from a fixed starting position toward their choice and click the button to record their choice as quickly as possible. Mouse trackers record the cursor's path from the initial point to the registered response, allowing researchers to investigate several additional response properties that cannot be studied in standard reaction time recording setups with physical response buttons.

In short, the phrase *hand in motion reveals the mind in motion* summarizes the underlying reasoning and the primary motivation for the mouse tracking paradigm (9). In the traditional reaction-time analysis, a motor response is considered an additive factor detachable from sensory and cognitive processes in the course of a decision. In contrast, dynamical approaches consider motor response as an *action in-flux* that is continuously adjusted via perceptual and cognitive processes over time. Therefore, if the online motor responses can be tracked with adequate sampling frequency, insights into perceptual-cognitive dynamics can be obtained (9), which is particularly important in judgment and decision-making tasks where the conflict resolution unfolds and is resolved on the fly as a response is being made (6).

Notwithstanding the several advantages provided by the mouse tracking methodology, recent studies illustrate the need for a thorough analysis of methodological problems, including the variance due to the placement of stimulus and response locations, the cursor speed setting, sampling rate, and the initial location of the cursor (11, 12). These studies called for conventions to aid the standardization of essential parameters for mouse tracking experiments. This study aims to contribute to these efforts by analyzing factors such as designating top versus bottom corners as response locations, handedness, and adjusting to the reversal of the response mapping in the context of a widely studied stimulus-response compatibility paradigm called the Simon Task. To the best of our knowledge, this study includes the first mouse tracking investigation of the reverse Simon effect.

METHODS

This study explores what additional insights could be gained from mouse-tracking compared to traditional response time analysis. For that purpose, three experiments were conducted to explore the Simon effect with a rich set of measures derived from mouse response trajectories. The traditional Simon task is concerned with stimulus-response compatibility, where a stimulus is presented to signal a button press with either the left or the right hand (13). The effect is due to the longer reaction time observed for spatially incompatible stimuli with the responding hand (14). In the current study, the classical Simon experiment was adapted for the mouse-tracking paradigm.

In mouse-tracking paradigms, hand movement dynamics are characterized by spatial attraction/curvature, complexity, velocity, and acceleration (9, 15). In a mouse-tracking experiment for a decision-making task including binary choices, the response options are typically placed in the top-left and top-right corners, and the starting position is fixed at the bottom-center at the onset of each trial. The participant registers his/her choice by dragging the cursor towards one of the corners and clicking on the response box without lifting the mouse. The path followed by the mouse cursor is recorded for each trial as the participant's response to that particular stimulus.

The MouseTracker software provides several measures, including the area under the curve (AUC), maximum deviation (MD), time to maximum deviation (MD-Time), and the number of x– and y-flips derived from mouse responses to help characterize hand motion dynamics observed on a trial-by-trial basis. These complexity measures are computed in reference to an idealized response path (Figure 1). MD refers to the maximum distance of the response curve from the idealized shortest response towards the same decision, AUC is the geometrical area of the region enclosed by the recorded and idealized paths, and MD-time refers to the elapsed time to reach the MD point during a trial. The x– and y-flips correspond to the number of reversals in direction along x– and y-axes, respectively.

The MD and AUC provide a measure of attraction by the alternative choice, where large values indicate hesitation or a higher degree of attraction towards the other choice. MD marks a point in the trajectory where the response gets oriented towards the outcome, which may be useful to characterize a critical point after which the trajectory converges on a response. The x-flips and y-flips capture the complexity of the mouse trajectories. When the unselected response is a strong attractor for the participant, the mouse trajectories tend to follow less smooth, more complex trajectories with fluctuations. The x– and y-flips aim to quantify the degree of fluctuations in the hand's vacillation between response alternatives along the corresponding axes.

The first experiment included a replication of Scherbaum et al.'s (5) mouse-tracking adaptation of the Simon task. In the second experiment, we modified this design by moving the response buttons to the bottom corners. In the third experiment, we implemented a mouse-tracking adaptation of the *reverse Simon Effect* (16), where we exposed participants to a specific direction-color mapping in the first half of the session (e.g., green-to-left and red-to-right), which is later reversed in the second half to observe the effects of this perturbation on the dynamics of the conflict resolution stage.

All the experiments were developed and conducted using the MouseTracker software (9). The experiments were conducted on a 15.6 inch standard PC laptop running Windows10. The mouse movements were recorded with a Logitech M105 mouse with a sampling frequency of 60 Hz. Before the experiment, the Edinburgh Handedness Test (17) was administered, which was not used as an exclusion criterion, but as a means to check if handedness influences the observed responses. Informed consent of the participants was obtained before the experiment. The study was approved by the METU Human Subjects Ethics Committee (Protocol No: 122-ODTÜ-2019).

RESULTS

Experiment 1

Participants. The sample consisted of 52 Turkish-speaking subjects (15 female) aged between 20 and 56 (*M*=28.21, *SD*=7.05, *Mdn*=22, *IQR*: 20–31). 47 out of 52 (94%) of the participants were right-hand dominant. Two out of the five left-dominant participants used the mouse with their left hand. All participants were using computers daily for their work and had either high-school or university level education.

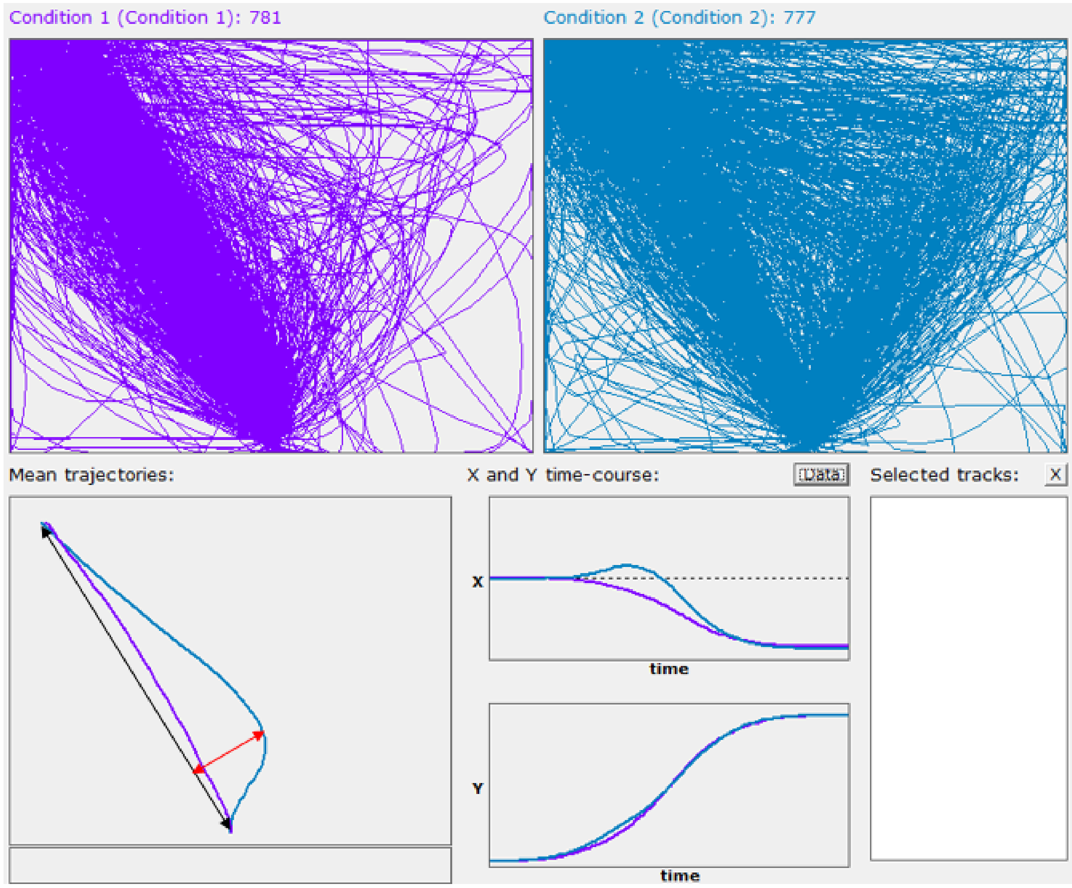

Figure 1. The output screen of a Mouse Tracker experiment that shows all SR-compatible and SR-incompatible trials for the left decisions. The bottom-left figure shows the average trajectories for these trials. The line with black arrows shows the idealized path, where the line with red arrows shows the max-displacement for the incompatible trials. The area enclosed by the black and blue lines defines the area-under-curve for the incompatible trials.

Procedure. During the experiment, participants performed a Simon task adapted for mouse-tracking. During each trial, a stimulus was displayed either to the left or right of a fixation cross located at the center of the screen. When the "Sol" (Left) message is observed, irrespective of its position with respect to the fixation sign, the participants were instructed to move the mouse to the top-left corner and left-click on the response button with the label "Sol" as quickly as possible (Figure 2). When the "Sağ" (Right) message is observed, participants were asked to respond towards the top-right corner in a similar way. The participants were told not to lift the mouse from the mouse-pad to ensure continuous, accurate recording of the hand movement. The stimulus was shown as soon as the start button is clicked, which initialized the mouse cursor's position at the center of the start button at the onset of each trial. Participants were given 2000 msec to respond to each stimulus. The experiment included 64 trials where the first 4 trials were used to familiarize the participant with the task. In the remaining trials, the participants were shown 15 trials each for the left-compatible, left-conflict, right-compatible, and right-conflict conditions in fully randomized order. The goal of the first experiment is to replicate the response-compatibility effect in a mouse-tracking task.

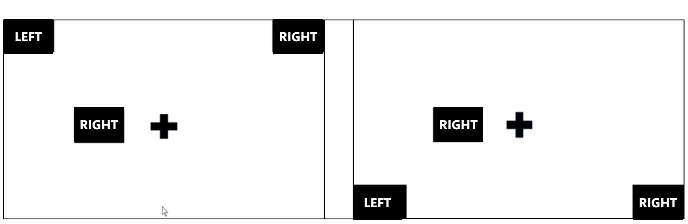

Figure 2. The screen layout used for experiment 1 (left) and experiment 2 (right). In both layouts, the cue and the target location are not spatially compatible with each other.

Results. Only in 5 trials participants clicked on the wrong button (% 0.016), so no trials were excluded from the analysis. The descriptive statistics for the dependent variables under consideration are summarized in Table 1 under condition (conflict vs. compatible) and position (left vs. right) columns. 2×2 repeated measures ANOVAs conducted for each dependent variable revealed a significant condition effect for Response Time (F (1.51)=49.91, MSE=7404.88, p<0.001, η_p^2=0.49), MD (F (1.51)=81.14, MSE=0.06, p<0.001, η_p^2=0.61), MD-time (F (1.51)=21.17, MSE=4894.23, p<0.001, η_p^2=0.29), AUC: (F (1.51)=108.46, MSE=0.11, p<0.001, η_p^2=0.68), x-flips (F (1.51)=20.08, MSE=0.54, p<0.001, η_p^2=0.28), and y-flips (F (1.51)=39.38, MSE=0.73, p<0.001, η_p^2=0.44).

A significant main effect of position was observed only for y-flips, F (1.51)=5.96, MSE=0.52, p<0.05, η_p^2=0.10. The interaction between condition and position was significant for only MD, F (1.51)=4.54, p<0.05, MSE=0.01, η_p^2=0.08. The position effect in y-flips is due to the higher number of y-flips observed during trials targeting the right corner. The significant interaction for max-distance is also due to the higher MD measure for right-conflict trials than left-conflict trials. These effects were unchanged when the analysis was repeated with only right-dominant participants.

Experiment 2

Participants. The sample consisted of 52 Turkish-speaking subjects (14

Table 1. Descriptive statistics for Experiments 1 and 2

		Top (Experiment 1)				Bottom (Experiment 2)			
		R-at-R	**L-at-L**	**R-at-L**	**L-at-R**	**R-at-R**	**L-at-L**	**R-at-L**	**L-at-R**
RT (msec)	M	1225.20	1205.83	1307.21	1292.43	1247.05	1255.73	1409.41	1368.28
	SD	273.65	255.81	259.71	287.37	264.06	247.42	282.63	256.97
MD	M	0.25	0.26	0.59	0.55	0.28	0.26	0.70	0.62
	SD	0.11	0.15	0.31	0.30	0.15	0.11	0.28	0.26
AUC	M	0.29	0.35	1.00	0.99	0.36	0.30	1.34	1.02
	SD	0.22	0.30	0.72	0.77	0.29	0.18	0.75	0.59
MD-Time	M	618.30	610.48	665.55	652.51	603.41	607.92	668.74	644.61
	SD	152.61	153.27	119.71	156.45	152.54	134.03	139.76	139.06
X-Flips	M	6.30	6.00	6.66	6.55	8.12	7.62	8.55	8.19
	SD	1.60	1.58	1.53	1.75	1.68	1.44	1.58	1.48
Y-Flips	M	5.00	4.90	5.89	5.50	7.11	6.52	7.96	7.73
	SD	1.32	1.25	1.65	1.50	1.54	1.44	1.64	1.56

RT, Reaction Time; MD, Maximum Displacement; AUC, Area Under Curve; MD-Time, Time to Maximum Displacement; X-Flips, Number of reversals in the mouse trajectory along the x-axis; Y-Flips, Number of reversals in the mouse trajectory along the y-axis; R-at-R, Right instruction placed on the right (compatible); R-at-L, Right instruction placed on the left (conflict); L-at-R, Left instruction placed on the right (conflict); L-at-L, Left instruction placed on the left (compatible).

females), aged between 18 and 50 (*M*=25.34, *SD*=7.48, *Mdn*=22, *IQR*: 20–31). 44 out of 52 (84%) participants were right-handed. Two out of the eight left-dominant participants used the mouse with their left hand. All participants were using computers daily for their work and had either high-school or university level education.

Procedure. The first experiment's design is modified so that the mouse cursor's starting position was located at the top-center, whereas the response choices were moved to left-bottom and right-bottom corners (Figure 1). The number and duration of randomized trials were kept the same as in the first experiment. This experiment aimed to explore if such spatial changes would have any effects on the response-compatibility effect. We aimed to observe if the significant interaction in MD and the main effect of position in y-flips would persist in this new layout.

Results. A ceiling effect was observed for accuracy, so the analysis focused on reaction measures. The datasets obtained from Experiments 1 and 2 were analyzed together to test for the main effect of change in the response target location. Three-way mixed ANOVAs were conducted to check for the effects of response position (left vs. right), response condition (compatible vs. conflict) as within-subjects, and the target location (i. e., whether the response buttons appear on the top or bottom corners) as between-subjects independent variables.

We found significant effect of condition on RT (F (1.102)=109.87, MSE=11638.12, p<0.001, η_p^2=0.52), MD (F (1.102)=241.15, MSE=0.05, p<0.001, η_p^2=0.70), MD-time (F (1.102)=49.05, MSE=4849.16, p<0.001, η_p^2=0.32), AUC (F (1.102)=180.87, MSE=0.34, p<0.001, η_p^2=0.64), x-flip (F (1.102)=34.01, MSE=0.70, p<0.001, η_p^2=0.25) and y-flip (F (1.102)=93.52, MSE=0.89, p<0.001, η_p^2=0.48). The effect of position was significant for MD (F (1.102)=6.98, MSE=0.02, p<0.05, η_p^2=0.06), AUC (F (1.102)=5.96, MSE=0.12, p<0.05, η_p^2=0.06), x-flips (F (1.102)=14.70, MSE=0.70, p<0.001, η_p^2=0.13) and y-flips (F (1.102)=16.74, MSE=0.88, p<0.001, η_p^2=0.14). The main effect of location was significant for only x-flips (F (1.102)=39.97, MSE=0.71, p<0.001, η_p^2=0.28) and y-flips (F (1.102)=60.72, MSE=0.67, p<0.001, η_p^2=0.37). A significant interaction of condition and location was observed for RT (F (1.102)=6.31, p<0.05, η_p^2=0.06), condition and position for MD (F (1.102)=12.04, MSE=0.01, p<0.01, η_p^2=0.11), and position and location for AUC (F (1.102)=11.91, MSE=0.06, p<0.01, η_p^2=0.10). Finally, the three-way interaction was significant for y-flips (F (1.102)=5.87, MSE=0.46, p<0.05, η_p^2=0.05). Only modest increases in effect sizes were observed when the analysis was repeated with only right-dominant participants.

Experiment 3

Participants. The sample consisted of 73 Turkish-speaking subjects (29 female) in the age-range 18 and 44 (*M*=26.71, *SD*=6.78, *Mdn*=24, *IQR*: 21.5–31). 65 out of 73 (89%) of the participants in the third experiment were right-hand dominant. Three out of the eight left-dominant participants used the mouse with their left hand. All participants were using computers daily for their work and had either high-school or university level education.

Procedure. A color-based version of the two-choice selection task was developed for the third experiment, where green and red were used to encode direction, which replaced "sağ" and "sol" as referents (Figure 3). The task included two stages where the positions of the color referents were switched in the middle of the experiment. After going through a familiarization stage, including four trials, subjects completed 32 trials with the first color-location mapping and then presented 32 more trials where the color positions were switched. This experiment's goal was to

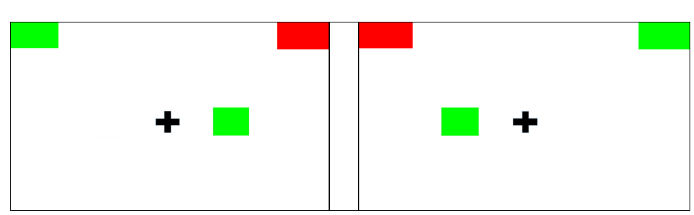

Figure 3. The screen layout used for experiment 3.

Table 2. Descriptive statistics for Experiment 3

		Pre				Post			
		R-at-R	**L-at-L**	**R-at-L**	**L-at-R**	**R-at-R**	**L-at-L**	**R-at-L**	**L-at-R**
RT (msec)	M	1296.30	1320.35	1382.82	1401.58	1303.69	1310.69	1395.63	1395.28
	SD	380.38	386.68	422.34	404.64	367.27	420.10	386.85	506.18
MD	M	0.28	0.28	0.61	0.63	0.31	0.30	0.69	0.62
	SD	0.22	0.20	0.30	0.30	0.20	0.23	0.34	0.30
AUC	M	0.37	0.38	1.10	1.07	0.42	0.39	1.29	1.06
	SD	0.53	0.51	0.80	0.78	0.51	0.48	0.96	0.80
MD-Time	M	604.75	619.11	586.66	620.18	587.86	607.69	619.19	630.25
	SD	211.00	236.67	143.96	201.17	169.23	217.96	199.14	226.99
X-Flips	M	6.91	7.01	7.18	7.48	7.19	7.05	7.42	7.52
	SD	1.74	1.80	1.60	1.64	1.61	1.74	1.70	1.79
Y-Flips	M	5.61	6.28	6.10	6.65	6.07	5.65	6.69	6.28
	SD	2.01	2.11	1.78	1.88	1.77	1.71	1.92	1.98

RT, Reaction Time; MD, Maximum Displacement; AUC, Area Under Curve; MD-Time, Time to Maximum Displacement; X-Flips, Number of reversals in the mouse trajectory along the x-axis; Y-Flips, Number of reversals in the mouse trajectory along the y-axis; R-at-R, Right instruction placed on the right (compatible); R-at-L, Right instruction placed on the left (conflict); L-at-R, Left instruction placed on the right (conflict); L-at-L, Left instruction placed on the left (compatible)

observe the so-called reverse Simon effect on mouse dynamics, which occurs when the response-compatibility mapping is reversed after a habituation period with the latter.

Results. We considered the last 16 trials of the first part of the experiment as an episode where a specific color-direction correspondence was established. The first 16 trials of the second part of the experiment as a transition period required the participant to adapt to the reversed color-direction correspondence (Table 2). Three-way repeated-measures ANOVAs were carried out to test the significance of the main effects due to expected response (left vs. right), the response condition (compatible vs. conflict), and the stage (pre vs. post).

We observed a significant main effect of condition for RT (F (1, 71)=17.12, MSE=62323.72, p<0.001, η_p^2=0.19), MD (F (1.71)=225.48, MSE=0.45, p<0.001, η_p^2=0.76), MD-time (F (1.71)=154.93, MSE=1094.19, p<0.001, η_p^2=0.69), AUC (F (1.71)=184.00, MSE=1.22, p<0.001, η_p^2=0.72), x-flips (F (1.71)=6.46, MSE=2.87, p<0.05, η_p^2=0.08) and y-flips (F (1.71)=15.71, MSE=2.57, p<0.001, η_p^2=0.18). The interaction of order and position was significant for only MD (F (1.71)=4.42, MSE=0.20, p<0.05, η_p^2=0.06), AUC (F (1.71)=5.77, MSE=0.45, p<0.05, η_p^2=0.08) and y-flips (F (1.71)=16.87, MSE=2.25, p<0.001, η_p^2=0.19). These effects were unchanged when the analysis was repeated with only right-dominant participants.

DISCUSSION

In this study, we adapted the well-known Simon and the reverse Simon experiments in a mouse-tracking setup to explore the potential of motor response measures derived from mouse data to investigate stimulus-response compatibility effects. Furthermore, we examined the effect of experimental design choices, such as placing the response buttons to the top or bottom corners on the observed mouse dynamics. Expectedly, the mouse trajectories were sensitive to the spatial compatibility among the stimulus and response, which was manifested in the significant differences observed between conflict and compatible trials in terms of classical reaction time measures and dynamical parameters related to mouse trajectories. We found that the effect sizes associated with the response-compatibility effect were higher for mouse-derived measures such as AUC and MD than simple Response Time. In other words, mouse dynamics measures provided stronger indicators for the response-compatibility effect than contrasts based on reaction time.

The added value of mouse-tracking is most vividly observed in measures that reveal the temporal dynamics of the response trajectories for each decision trial, which also have some implications for experiment design considerations. For instance, the first experiment yielded an interaction effect for the MD measure, suggesting that the participants were more hesitant to click on the right button when the cue "right" was displayed to the left of the fixation cross. In contrast, smaller MD values were observed for the "left" responses in the conflict condition. Moreover, we observed higher y-flip averages for right button clicks during conflict trials, suggesting that participants followed more complex trajectories than responses towards the left. The difference in MD and y-flips among left and right responses vanished in the congruent trials. We observed the same effects with similar effect sizes when we focused on only the right-handed participants' data. In sum, these results suggest that clicking on the left and right corners to register a decision may bring some additional variability, especially in those trials where the choice alternative is a strong attractor (e.g., conflict condition in the Simon task), whereas the difference is negligible when the alternative is a weaker attractor.

In order to test if the difference observed between left and right responses in conflict situations had something to do with their location at the top, we conducted a follow-up experiment including a flipped layout where participants started at the top center and moved the cursor towards the bottom left or right corners to register their decision. In this version, we again observed a strong stimulus-response compatibility effect across all dependent variables, suggesting that the Simon effect is not influenced by the change in the screen layout. However, we found that it took longer for the participants to register their decisions as compared to the layout used in the first experiment. Finally, we observed a similar asymmetry between right and left responses recorded in conflict trials in terms of MD and y-flip measures. When the sample is filtered to right-handed participants, only modest increases in effect sizes were observed. In short, the location change resulted in an overall increase in reaction time and mouse dynamics measures for the top-to-bottom-corner layout.

The findings of experiments 1 and 2 corroborate with recent methodological studies on mouse-tracking, stating that mouse measures can be influenced by the experiment's layout (11, 12). Our results indicated that right and left responses might not necessarily follow symmetric paths, especially during conflict trials where the alternative choice is a strong attractor in contrast to compatible trials. Similar lateralization effects were previously observed in the Simon task's auditory variant (18, 19). Since button presses mask the underlying motor dynamics, such an asymmetry was not previously reported in the classical visuospatial version of the Simon task.

Experiment 3 focused on the reverse Simon effect, where participants were first trained on a specific color-response pattern, which was inverted in the middle of the experiment to observe the adaptation effects and eventual reversal of the stimulus-response compatibility relationship. Reaction time analysis revealed a significant difference between compatible and conflict conditions, but the delay in responses during adaptation resulted in reduced effect size, and no other effects were detected due to the transition and position. Similarly, the MD and AUC measures revealed a significant difference for compatibility conditions with larger effect sizes than RT, yet they yielded only marginally significant interaction of compatibility and order. The reversal of the Simon effect was most vividly demonstrated by the y-flips, which indicated the change in the complexity of the trajectories during the transition period.

To sum up, the results obtained from the three experiments suggest that the mouse-tracking paradigm offers important advantages for exploring decision dynamics compared to reaction time analysis. The measures' sensitivity also revealed asymmetries in responses towards the left and right corners in the conflict condition, which was not visible in reaction time contrasts. Such differences also raise caution about experimental design considerations for more complex decision-making scenarios where saddle differences may be masked due to the asymmetry between left and right trajectories, especially when the choice is a strong attractor. Counterbalancing response locations could be one way to mitigate the effects of such an asymmetry on mouse-tracking measures. Further studies are needed to better account for the possible reasons underlying this asymmetry. Handedness was a factor we aimed to explore, but since our sample predominantly included right-handed participants, our analysis was not conclusive regarding the effects of handedness. A study including an equal number of left and right-handed participants might better identify this asymmetry and handedness relationship. The frequency of computer use could be another factor that can be explored in a future study, which may partly account for the bias towards the left mouse trajectories.

The mouse-tracking methodology may have practical implications for neuroscience and neuropsychiatry studies focusing on neural underpinnings of decision-making processes and differences among pathological and control cases. For instance, the process of resolving a choice trial with a strong contextual attractor may not have the same influence on a schizophrenia patient, who is known to have difficulty reacting to contextual information (20). The dynamical features of mouse trajectories may also be subjected to causality analysis with neural activation patterns including ventromedial prefrontal and striatum regions facilitating valuation of choices and lateral prefrontal and parietal regions claimed to be involved with making a choice (21). Finally, excessively non-smooth mouse trajectories may indicate motor and cerebellum deficits, where reversals and tremors in the trajectories can be used for diagnostic purposes (22).

Committee Approval: The study was approved by the METU Human Subjects Ethics Committee (Protocol No: 122-ODTÜ-2019).

Informed Consent: Informed consent of the participants was obtained before the experiment.

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