Malaysian Journal of Ergonomics 2020, Vol. 2(1): 1 – 10

**ORIGINAL ARTICLE**

# Simon Says: The Influence of Handedness on Simon Effect and Considerations for Ergonomics Research and Practice

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*Studies have established that left and right actions are carried out faster when they spatially correspond to the stimulus signalling them, demonstrating the Simon effect. While the focus has been primarily on investigating this effect with a wide range of stimulus variations and cognitive abilities, limited research is available on investigating the influence of handedness on performance in the Simon task. The present study hypothesised that reaction times in the Simon task would differ across three groups (left-handed: n = 29, right-handed: n = 30, and ambidextrous: n = 26). Participants completed an online-based Simon task, in which they responded to the direction of left or right-pointing arrow appearing left or right from a fixation point. The Simon effect was larger in right-handed participants when the position of the arrow and the direction of the arrow were similar. Right-handed participants were also slowest in all conditions, irrespective of the position of the stimuli. However, the average speed of correct responses and percentage errors did not significantly differ when compared between the handedness groups. Further analyses showed that reaction times were fastest in the congruent condition and slowest in the incongruent condition. The results are discussed in light of the implications that they pose for ergonomics research and practice. Recommendations for future work are also presented.*

**Keywords: Simon effect, handedness, human-machine interfaces, reaction times**

## 1.0 Introduction

Stimulus-response compatibility and incompatibility effects [1] have long been investigated in ergonomics to design better human-machine interfaces or to discover optimal positions of operators. Good interfaces are typically designed to display information that matches the types of responses users should make. For instance, present car signal indicators are purposely set out to flash right when turning right and flash left when turning left. Similarly, many buttons and handles are positioned in a stimulus-response compatible form. Studies [2] [3] have shown that congruent and incongruent stimulus mapping differed in reaction times in such a way that a compatible mapping of stimulus and response location yields faster reaction times than does an incompatible mapping. A similar effect could also occur when stimulus location matches the response location than when it was not. In other words, people are faster and more accurate when responding to a stimulus that occurs in the same relative location as the physical response. This corresponding effect is known as the Simon effect [4].

Several explanations have been proposed to account for Simon effect. This includes interference to the response-execution stage [5], interference to the perceptual-encoding stage [6], attentional phenomenon arising from the interaction between two parallel and distinct processing routes [7], or automatic activation of the response that is triggered by the stimulus location [8]. Among the many factors that have been investigated in the literature on Simon effect, handedness is one of the few that requires attention. Defined as the "*preferred hand used for a motor activity (i.e., manual preference) or the hand most skilful at performing a task (i.e., manual proficiency")* [9], handedness is a significant feature of human motor behaviour and is influenced by many interacting factors such as genetics, biological, parental education, imitation behaviour, socio-environmental, and cultural, among others [10]. The most common way of categorising handedness is to classify information from hand preference questionnaires into three main categories based on a continuum ranging from strongly right-handed to strongly left-handed, with ambidextrous in the centre [11].

Studies have shown that the Simon effect was larger in the field where the dominant hand was operating [12] [13]. More specifically, the effect was greater on the right side for right-handers and on the left side for left-handers while ambidextrous people showed a symmetrical pattern. [12] also found that the advantage of the dominant hand increases with the average speed when compared to the non-dominant hand. This hand-centred attentional bias indicates that spatial attention is influenced by constant spatial cues, that is, by the location of the dominant hand [14]. Recent studies have further demonstrated that while right-handed people produced a larger Simon effect for stimuli at the right location than for stimuli at the left location, this relation was not evident for left-handers [2]. Left-handed people are also found to have an advantage over the right-handed in the up-left or down-right mapping, demonstrating orthogonal Simon effect [15]. All these studies, therefore, indicate that handedness might affect the way people respond to stimulus locations that are oriented congruently and incongruently with respect to the response locations.

While studies have examined a number of variables in relation to Simon effect (as discussed above), these studies are confined to certain localities only such as the United States, United Kingdom, and selected European countries. In addition, the majority of participants in these studies were either White, Black, or Hispanic; thus limiting the extent to which the effect can be fully understood within diverse cultural settings. A study by [16], for example, has demonstrated that racial similarity and dissimilarity could influence the reaction time and response selection in a Simon task. Hence, investigating the variation of Simon effect in other ethnicities may be a mechanism for discovering further explanation for this phenomenon.

Except for few studies, e.g., [16] and [17], there has been scant research looking at race or ethnicity, particularly on performance in the Simon task in Malaysia or among the Malay ethnicity. Therefore, examining this effect could aid understanding of how handedness may relate to Simon effect within this context and bring further advances to the field. Given this scenario, the present study investigated the influence of handedness on Simon effect in Malaysian Malays, with the percentage of errors, average speed of correct responses, and reaction times as the measured variables. It is hypothesised that handedness would influence performance in the Simon task in that there will be differences in the reaction times of the three groups, i.e., left-handed, right-handed, and ambidextrous.

## 2.0 Methods

Twenty-nine left-handed (Male = 15, Female = 14), 30 right-handed (Male = 17, Female = 13), and 26 ambidextrous (Male = 12, Female = 14), participants took part in this study that utilised a between-subjects experimental design. They were recruited based on their responses to the Handedness Questionnaire [18] that was adapted from [11], which was administered before the experiment took place. All participants were 18 years or older ($M_{age}$ = 25.15, $SD_{age}$ = 6.57), hold a valid driver license, and with no history of motor function defects. They also had similar levels of education (i.e., undergraduate degree). This inclusion criterion was adopted to control for potential confounding effects resulting from differences in education and intelligence levels. Additionally, the sample included Malays only to control for any possible effect of race or ethnicity.

The experiment was conducted individually on standard desktop computers at the university's experimental laboratory. Upon arrival at the lab, each participant was briefed about the nature and procedures of the experiment. After giving their informed consent, they filled out the Handedness Questionnaire [18], and then were asked to do the Simon task online at PsyToolkit [19], which is free to use at http://www.psytoolkit.org. The effectiveness and viability of PsyToolkit for conducting psychological experiments have been established in the literature, e.g., [20] and [21]. In this task, participants were presented with a series of directional arrows. These arrows are pointed either left or right and appeared either on the left side or the right side of the screen. Therefore, arrows could either be congruent with spatial location, i.e., a left-pointing arrow on the left side of the screen (LALS) and a right-pointing arrow on right side of the screen (RARS), or incongruent, i.e., a left-pointing arrow on the right side of the screen (LARS), and a right-pointing arrow on the left side of the screen (RALS). Participants were told to respond as fast and accurately as possible by pressing a key corresponding to the spatial location of the arrow on the screen, regardless of the direction in which the arrow was pointing. After a training block as a practice, participants completed the experiment, and their reaction times (in milliseconds) for each condition were recorded. The average speed of correct responses and percentage errors were also calculated.

## 3.0 Analysis

Data collected were analysed using IBM SPSS 22.0; first by descriptive statistics to examine the general data distribution, then by a series of one-way analysis of variance (ANOVA) to locate significant differences, and followed by comparisons of the reaction times for congruent and incongruent categories of the Simon task.

## 4.0 Results

***Descriptive analyses:*** In general, right-handed participants showed (i) higher average speed of correct responses, indicating slower performance, (ii) longer mean reaction times across the LALS, RARS, LARS, and RALS conditions, and (iii) the percentage of errors of 5% (see Table 1 and Figure 1 to Figure 4). Meanwhile, left-handed participants had the fastest average speed of correct responses but a greater percentage of errors. The average speed of correct responses for ambidextrous participants was 505.19 milliseconds, with the lowest percentage of errors when compared to the other two groups.

Table 1: Descriptive statistics and ANOVA results

| | **Handedness** | ***n*** | ***M*** | ***SD*** | ***df*** | ***F*** | ***p*** |
|---|---|---|---|---|---|---|---|
| Percentage of errors | Left | 29 | 6.35 | 5.43 | 2, 82 | 1.01 | .37 |
| | Right | 30 | 5.00 | 3.55 | | | |
| | Ambidextrous | 26 | 4.85 | 3.92 | | | |
| | Total | 85 | 5.41 | 4.38 | | | |
| | **Handedness** | **Reaction Time (milliseconds)** | | | | | |
| | | ***n*** | ***M*** | ***SD*** | ***df*** | ***F*** | ***p*** |
| Average speed of correct responses | Left | 29 | 501.48 | 73.46 | 2, 82 | 2.22 | .12 |
| | Right | 30 | 540.47 | 82.19 | | | |
| | Ambidextrous | 26 | 505.19 | 78.15 | | | |
| | Total | 85 | 516.38 | 79.19 | | | |
| LALS | Left | 29 | 468.48 | 68.412 | 2, 82 | 4.35 | .02** |
| | Right | 30 | 529.07 | 84.33 | | | |
| | Ambidextrous | 26 | 491.50 | 85.74 | | | |
| | Total | 85 | 496.91 | 82.83 | | | |
| RARS | Left | 29 | 488.62 | 74.73 | 2, 82 | 1.28 | .28 |
| | Right | 30 | 515.47 | 83.57 | | | |
| | Ambidextrous | 26 | 482.77 | 89.47 | | | |
| | Total | 85 | 496.31 | 82.85 | | | |
| LARS | Left | 29 | 524.83 | 87.31 | 2, 82 | 2.00 | .14 |
| | Right | 30 | 564.83 | 93.42 | | | |
| | Ambidextrous | 26 | 522.96 | 89.39 | | | |
| | Total | 85 | 538.38 | 91.21 | | | |
| RALS | Left | 29 | 530.52 | 95.86 | 2, 82 | .77 | .47 |
| | Right | 30 | 558.30 | 88.48 | | | |
| | Ambidextrous | 26 | 538.15 | 81.32 | | | |
| | Total | 85 | 542.66 | 88.76 | | | |
| Congruent category | Left | 29 | 957.10 | 135.59 | 2, 82 | 2.66 | .08 |
| | Right | 30 | 1044.53 | 160.11 | | | |
| | Ambidextrous | 26 | 974.27 | 165.93 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | 85 | 993.21 | 157.08 | | | |
| Incongruent category | Left | 29 | 1055.35 | 174.38 | 2, 82 | 1.41 | .25 |
| | Right | 30 | 1123.13 | 175.58 | | | |
| | Ambidextrous | 26 | 1061.12 | 161.49 | | | |
| | Total | 85 | 1081.04 | 171.83 | | | |

** $p < .05$

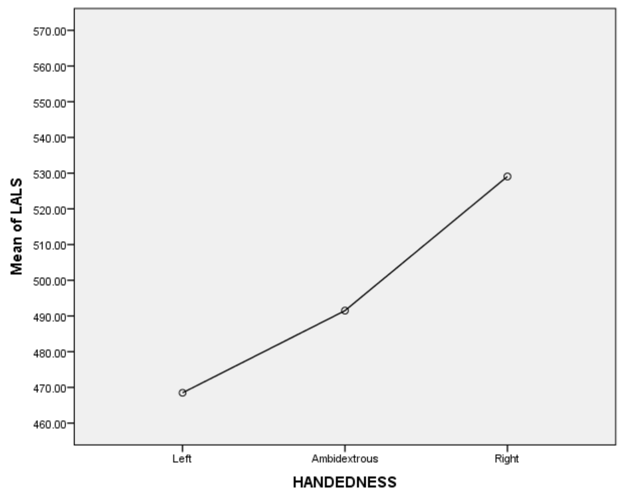


Figure 1: Means plot of reaction times for handedness groups in LALS condition

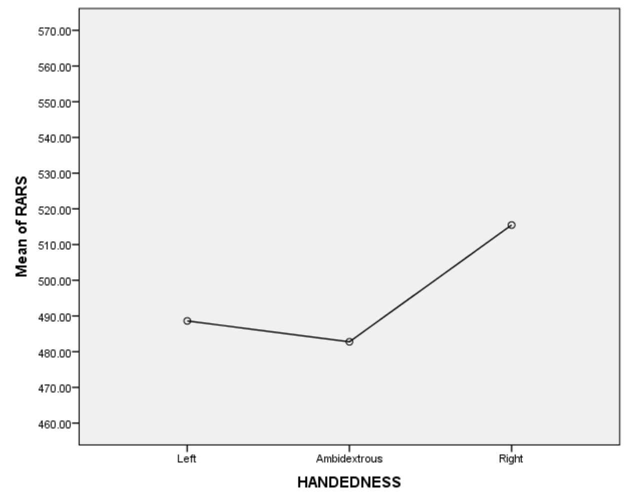


Figure 2: Means plot of reaction times for handedness groups in RARS condition

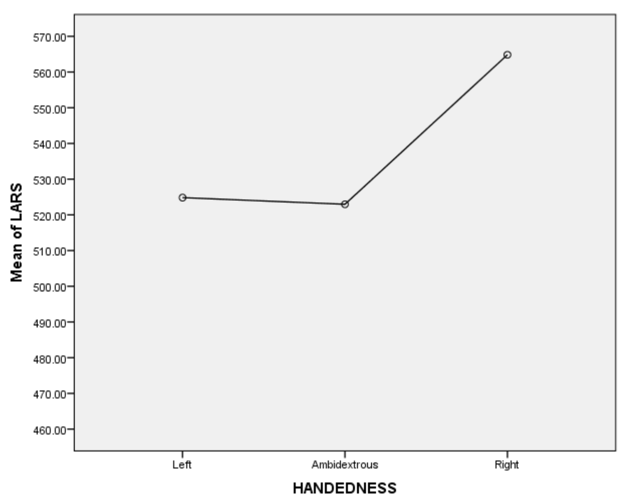


Figure 3: Means plot of reaction times for handedness groups in LARS condition

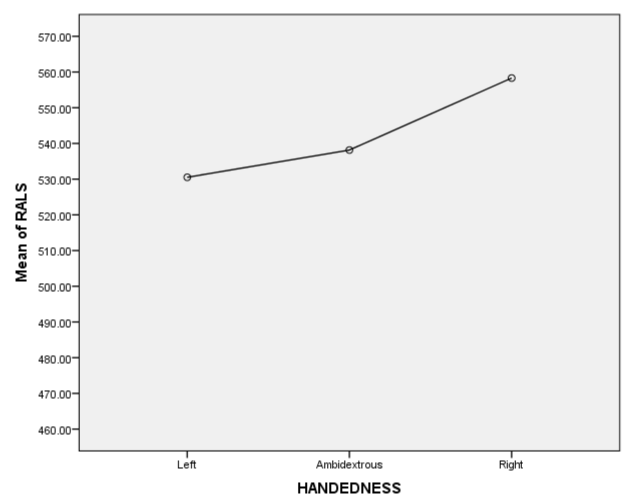


Figure 4: Means plot of reaction times for handedness groups in RALS condition

***One-way analysis of variance (ANOVAs):*** Four separate ANOVAs were conducted to compare the reaction times of the left-handed, right-handed, and ambidextrous participants for each experimental condition. First, the results indicate that when the arrow pointed left was presented on the left side of the screen (LALS), there were statistically significant differences between the handedness groups, $F(2, 82) = 4.35$, $p = .02$). Tukey's HSD tests showed that reaction times were significantly longer for right-handed participants in the LALS condition ($p = .01$) compared to the left-handed participants, suggesting that the Simon effect was more pronounced for the former group than for the latter. Comparisons of reaction times between left-handed and ambidextrous participants ($p = .54$) as well as between right-handed and ambidextrous participants ($p = .19$) were not statistically significant. Analyses of the subsequent one-way ANOVAs showed that within each handedness group, reaction times did not significantly differ across the experimental conditions. Similarly, non-statistically significant differences were obtained when average speed of correct responses and percentage errors were compared between handedness groups, suggesting that these two measures were not due to differences in handedness (see Table 1 for these results).

***Congruent vs. Incongruent categories:*** In the final analysis, data for LALS and RARS were combined into one category, named as Congruent. A similar procedure was carried out for LARS and RALS data, creating a second category, i.e., Incongruent. These categories were then compared using paired samples *t*-test, and the results revealed a significant difference in the reaction times between the Congruent ($M = 993.21$, $SD = 157.08$) and Incongruent ($M = 1081.04$, $SD = 171.83$) categories, $t(84) = -10.37$, $p < .001$. However, one-way ANOVAs evaluating reaction times of the left-handed, right-handed, and ambidextrous participants were not statistically significant in both categories (see Table 1, Figure 5, and 6).

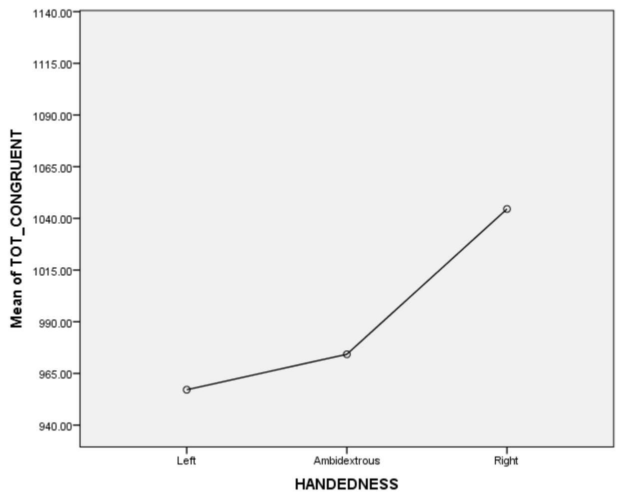


Figure 5: Means plot of reaction times for handedness groups in Congruent category

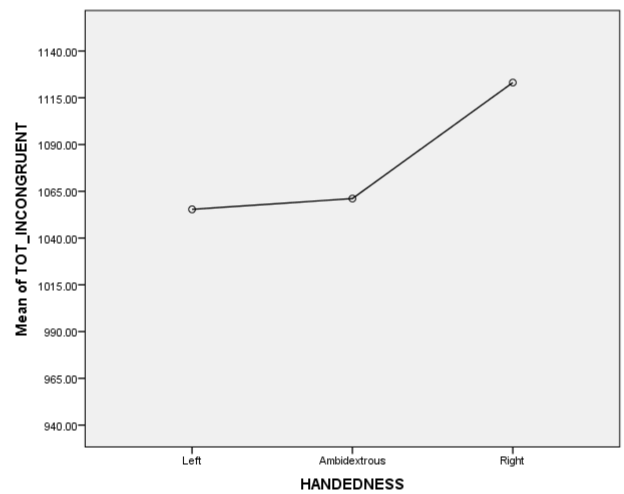


Figure 6: Means plot of reaction times for handedness groups in Incongruent category

## 5.0 Discussion

This study sets out to investigate the role that handedness plays in the Simon task. In particular, the Simon effect was analysed for three groups, i.e., left-handed, right-handed, and ambidextrous participants under four experimental conditions of which two are stimulus-response-congruent (LALS and RARS) while another two are stimulus-response-incongruent (LARS and RALS).

Results showed a larger Simon effect on dominant hands in terms of reaction times when the position of the arrow and the direction of the arrow were similar, with right-handed participants took significantly longer to respond in the LALS condition than left-handed participants. Descriptive statistics were also suggestive of a similar trend where correct responses were fastest for left-handers compared to right-handers and ambidextrous participants, though not statistically significant. Further, right-handed participants, on average, were slowest in all conditions, irrespective of the position of the stimuli. These results support earlier findings that the Simon effect is larger and significant for stimulus on the dominant hand side [12] [13]. One possible explanation for these results is that a bias in attention shifting occurred when the dominant hand was in use [12]. According to this account, the shift of attention in the visual field would determine the strength of spatial codes and thus, the magnitude of the Simon effect

[22]. Consequently, a larger Simon effect for the dominant hand is observed because spatial attention processes are more efficient in the dominant hand than in the non-dominant hand [22].

Our results also confirmed previous findings that reaction times were fastest in the congruent condition, whereas responses were slowest in the incongruent condition. It has been suggested that congruent condition enables facilitation process whereby the matching information between the stimulus and the response speeds up responses, which is manifested in the shortened reaction times [23] [24]. On the other hand, performance is slowest in the incongruent condition due to interference process where there is a conflict between the stimulus and response that needs to be suppressed. This, in turn, results in longer reaction time [23] [24]. Interestingly, handedness does not seem to have affected reaction times either in the congruent or incongruent conditions. Despite this result, left-handed participants gave the fastest reaction times, followed by the ambidextrous and right-handed participants in both conditions. The enhanced performance of the left-handed participants may partly be due to the differences in age or other factors such as visuo-motor integration ability and upper limb-hand motor function, which were not investigated in this study. Future research on the potential influence of these factors on the Simon effect is thus suggested.

## 6.0 Conclusion

Taken the results altogether, this study provides evidence for the influence of handedness on the Simon task. Two broad implications for ergonomics research and practice are suggested. First, because Simon effect has an important impact on attention-demanding activities, design of interfaces for activities that involves driving, mechanical work, or manufacturing should take this effect into consideration. To ensure faster and accurate reaction towards a stimulus, it is strongly recommended that the stimulus is placed on the side that corresponds to the response and to align responses on the right with movements on the right and responses on the left with movements on the left.

Second, handedness, responding hand, visual-spatial ability, as well as cognitive flexibility all contribute to different responses in examining the spatial relationship and cognitive control functions in individuals. As the present study is limited to participants from only one ethnicity in Malaysia, future research would benefit from investigating the Simon effect with a wider range of participants to further enhance the conceptualisation and understanding of the phenomenon across a variety of individuals and subpopulations.

## Acknowledgements

The author thanks all students and participants for their involvement in the study. This study was self-funded, and the author declares no competing financial and conflicting interests.

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