MULTITASKING:

The Impact of Spatial and Verbal Working Memory on the Simon Effect

Student Author

Emerald Obie conducted this research as a graduating senior in brain and behavioral sciences in the College of Health and Human Sciences at Purdue University. She worked in the Psychological Sciences department in both cognitive psychology and behavioral neuroscience during the last couple of years as an undergraduate. During her junior and senior year, she worked very closely with Robert W. Proctor and studied the Simon effect in human subjects. She continues to work as a part-time researcher today while continuing her education as a PhD student at Purdue. She is studying cognitive psychology and hopes to pursue a career as a research professor in the cognitive field.

Mentor

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Abstract

The Simon effect occurs when a person's reaction time to a stimulus feature such as color is quicker and more accurate when the stimulus occurs in a location that corresponds with the physical response rather than one that does not. For example, if a red circle appears on the right side, the response is the faster when red is assigned to a right physical response than when it is assigned to a left physical response. This effect of irrelevant stimulus location is presumed to be a consequence of having the spatially defined responses active in working memory (WM). Zhao, Chen, and West (2010) studied the influence of WM on this phenomenon using simple spatial or verbal exercises called memory loads. Requiring participants to maintain a verbal memory load eliminated the Simon effect, but requiring them to maintain a spatial memory load had no influence on it. My study was designed to replicate and extend Zhao et al.'s study. The only differences were that the participants were from the United States rather than China, and the verbal material was English letters rather than Chinese characters. Experiment 1 showed that I was able to obtain the Simon effect in a baseline condition for which there was no memory load. In Experiment 2, prior to each trial of the Simon task, participants were presented a set of four letters or four locations of a grid, which they were to remember for a memory test given after making the response for the Simon task. With this method, the working memory loads in the two conditions were more comparable than in Zhao et al.'s study. Results show that the Simon effect was eliminated during the spatial task but not during the verbal task. Possible reasons for the discrepancy between my results and those of Zhao et al. are the demographic background of participants and the stimuli used for the studies. Knowing conditions under which irrelevant location correspondences influence performance is important for design of human-machine interfaces that enable fast and accurate operation.

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Keywords

cognitive psychology, Simon effect, working memory, spatial memory, verbal memory

INTRODUCTION

In our everyday routine, the act of problem solving is important. We undergo this process from trivial issues to problems that require special attention. According to H. A. Simon (1978), problem-solving behavior involves three foundational elements, one of which is information processing. Per the information-processing theory, there are three stages involved in making decisions: stimulus identification, response selection, and response execution (Proctor & Van Zandt, 2018). Response selection specifically involves the choice between alternative possible actions that one could take.

Response selection was the primary topic of the book *Stimulus-Response Compatibility: An Integrated Perspective*, which included an influential chapter by J. R. Simon on "The Effects of an Irrelevant Directional Cue on Human Information Processing" (Simon, 1990). These effects are known collectively as the *Simon effect* (see Lu & Proctor, 1995)—a lengthening of reaction times (RT) when stimuli occur in a location that is incongruent with that of the response assigned to a relevant stimulus dimension (often color) compared to when they occur in the congruent location. This effect is one of the paramount phenomena that influence response selection. Studies that focus on the Simon effect look at spatial compatibility very closely under various conditions and investigate whether stimuli performance is poorer when the stimulus and response locations are incongruent than when they are congruent, even though stimulus location is irrelevant. In the present study, I investigated this effect further by researching how working memory tasks influence the Simon effect.

Multitasking is heavily studied in cognitive psychology, and there are studies that provide evidence that doing two cognitive tasks at once can be strenuous for an individual inside and outside of the laboratory (Redick, 2016). Zhao, Chen, and West (2010) conducted a study that explored the connection between working memory—that is, the nature of contents that must be maintained for a short time—and the Simon effect. In their article, they discuss their findings about working memory loads, which they predicted would influence performance of choice RT tasks presented to participants because keeping the task goals in working memory is likely essential to occurrence of the Simon effect. The types of memory loads considered were spatial and verbal.

Spatial working memory was studied because previous studies by Ulrich Ansorge and Peter Wühr (2004) found evidence that working memory is a

critical component for processing the spatial properties of the Simon task. Ansorge and Wühr found that during a condition where the spatial working memory stimuli were placed horizontally, the Simon effect was eliminated. To explore this issue, Zhao et al. (2010) used black squares that occupied randomized locations for the participant to memorize before the Simon task was presented. The idea is that this spatial memory load would make it difficult to encode spatial information of the Simon task trials.

Zhao et al. (2010) also studied a condition with a verbal memory load because a prior study by Kim, Kim, and Chun (2005) found a verbal load to influence a similar effect called the *Stroop color-naming effect*. The Stroop color-naming effect occurs when one is supposed to say the color in which a color word is presented, but not the spelled word. For example, the participant would see the word "BLUE" and the letters would be the color orange. In order to give an accurate answer, they would have to say orange and not blue. As one can imagine, this is quite difficult to do quickly as well as accurately. Kim et al. (2005) found that when verbal working memory was occupied, the Stroop color-naming effect was eliminated. These findings led Zhao et al. (2010) to test whether a verbal memory load would have a similar influence on the Simon effect. In Zhao et al.'s experiment, the verbal load was imposed by presenting seven Chinese characters to Chinese participants before the Simon task began, which were to be held in working memory for a subsequent recognition test.

Zhao et al. (2010) conducted two experiments. The first was a choice-reaction task that included congruent and incongruent locations that required a quick and accurate response from the user. After determining that a significant Simon effect was found, they implemented the two memory-load conditions: spatial and verbal. The spatial memory task included four squares in randomized locations, which the participant had to memorize for a later memory test. The verbal task included seven Chinese characters to be memorized for a later memory test (Figure 1). These conditions were varied between subjects, meaning the type of memory test was varied. A participant would not receive a spatial and a verbal memory test in one sitting. Results showed that the spatial memory task had no influence on the Simon effect, whereas the verbal memory task eliminated the Simon effect. After obtaining the results from Experiment 1, Zhao et al. tested whether they would obtain different results if the spatial stimuli and Chinese characters were placed vertically instead of horizontally (Figure 2). They believed that the results occurred because of placement overlap between the spatial and verbal tasks. However, the new results indicated the same findings as the previous experiment.

In Zhao et al.'s (2010) study, the spatial memory load was four items, whereas the verbal memory load was seven items. Therefore, the difference in influence on the Simon effect could have been due to the size of the memory load rather than the

Figure 1. (A) Zhao et al.'s Experiment 1 spatial sequence (randomized). (B) Zhao et al.'s verbal sequence (horizontal).

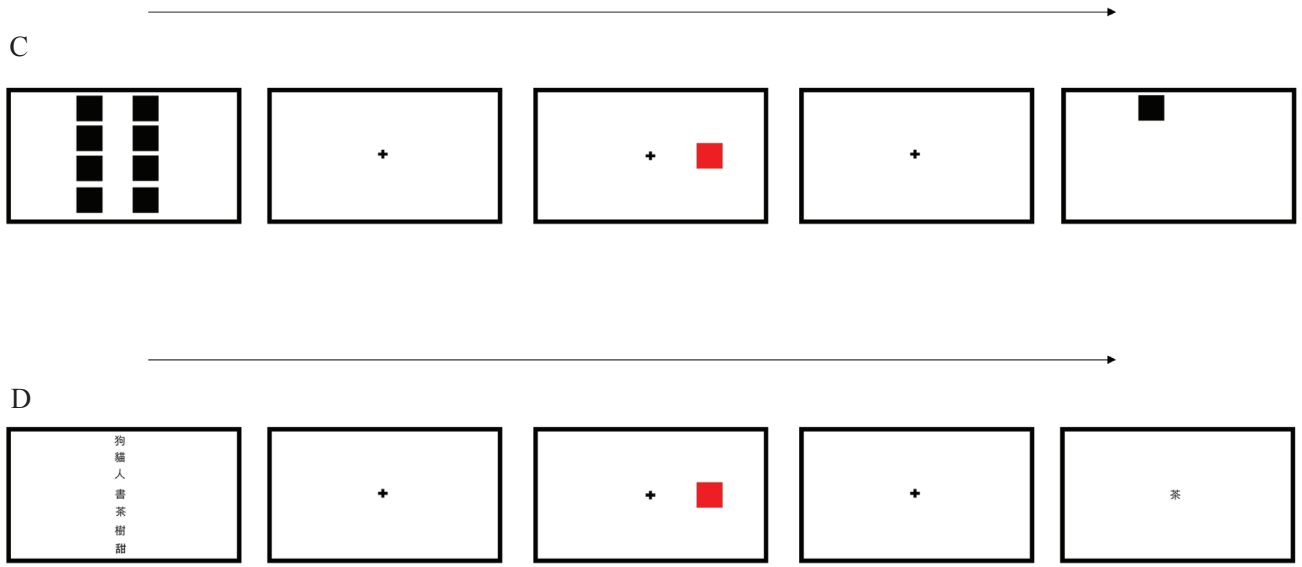

Figure 2. (A) Zhao et al.'s Experiment 1 spatial sequence (vertical). (B) Zhao et al.'s verbal experiment sequence (vertical).

spatial versus verbal mode. Also, because the verbal stimuli were Chinese characters and the participants were native Chinese speakers, whether a sample of English-language speakers in the United States would show similar results with a verbal memory load of alphabetic characters would also be informative. Therefore, the purpose of the present study was to explore this influence of working memory load further, with the specific goal of determining whether similar findings to those of Zhao et al. could be obtained from English-speaking participants at Purdue University using spatial and verbal memory loads equated in size.

Experiment 1 included the same choice-reaction task except that the colors of the squares differed: Zhao et al. (2010) presented red and blue squares, whereas I used red and green squares (which are commonly used in Simon tasks). The purpose of Experiment 1 was to establish that these stimuli yielded a Simon effect when there was no memory load. After establishing that the stimuli yielded a Simon effect, I used the same stimuli for the Simon task in Experiment 2, in which participants performed that task in the context of a spatial or verbal memory load, similar to Zhao et al. Instead of presenting participants with seven meaningful Chinese characters in the verbal memory load condition, I presented four randomized English letters, with which the English-speaking participants would be familiar. This verbal memory set was the same size as the spatial memory load condition in both Zhao et al.'s study and the present Experiment 2.

EXPERIMENT 1—SIMON TASK ALONE

Method

Participants. Eighteen Introductory Psychology students (ages 18–22 years) from Purdue University participated in this study for experiment credits. All experiments described in this paper were conducted under a protocol approved by the Institutional Review Board at Purdue University. I obtained informed consent at the beginning of the experiment, and credit was given at the end.

Design. The experiment was manipulated within subjects. The experiment included one practice block of 12 trials and two experimental blocks of 96 trials.

Materials and procedure. I conducted the experiment in a dimly lit room on a Dell PC that was controlled by E-Prime 2.0 software. The participants viewed the display from a distance of approximately 65 cm. During the experiment, participants responded by pressing one of two keys on the keyboard. The stimuli for this were two 1-inch colored squares (red and green) that appeared 3.8 cm to the left or right of a central fixation stimulus (a + sign). There were equal numbers of red and green stimuli shown to the participant.

After the participant was given instructions, she or he performed the Simon task for one practice block of 24 trials and two experimental blocks of 96 trials each. A trial began with onset of the fixation cross, which remained on throughout the trial. Six-hundred

Figure 3. Sequence of displays for Experiment 1.

ms after its onset, a red or green stimulus was presented to the left or right of fixation (Figure 3). The stimulus remained until a response was recorded. Half of the participants were instructed to press the "Q" key for red with their left index finger and "O" key for green with their right index finger. The mapping of colors to response keys was reversed for the remaining participants. The next trial began immediately after the response was made. There was one within-subject factor: congruency (congruent or incongruent relation of stimulus location and response location).

Results and Discussion

Trials with RT shorter than 150 ms or longer than 1,500 ms were eliminated from analyses (.003% of the trials), and only correct responses were included in the analysis of RTs. I then analyzed mean RTs for congruent and incongruent trials. A significant Simon effect of 10 ms was obtained [$F(1,17) = 5.32$, $p < .05$, $\eta^2 = .24$]. The mean RT for congruent trials was 445 ms, and that for incongruent trials was 455 ms. The mean percentage error for congruent trials was 1.7% and for incongruent trials was 1.9%, which was a nonsignificant difference, $F < 1.0$.

The specific task conditions used in this study thus yielded a Simon effect when no memory load was imposed. Although statistically significant in the RT data, this effect was smaller than that found by Zhao et al. (2010) in their single-task control condition (19.5 ms and 1.4%). This difference may be due to participants performing the Simon task both alone and in the context of one of the working memory tasks in Zhao et al.'s experiment, compared to only performing the Simon task in the present Experiment 1. The main point is that Experiment 1 showed a Simon effect for the colored stimuli I used, which allowed me then to test whether working memory loads influence the Simon effect.

EXPERIMENT 2—SIMON TASK AND WORKING MEMORY LOADS

Experiment 2 was based on the study done by Zhao et al. (2010), but differed in the following ways. The participants in Zhao et al.'s study were all of Chinese descent and familiar with the Chinese language. Most of the participants for the present study were native English speakers; anyone who was not was fluent in the English language was not tested. For the verbal working memory load, Zhao et al. presented Chinese characters in a series of seven to the participants to memorize. In contrast, the present study displayed four English letters to the participants for the verbal memory load, to equate the number of letters with the number of positions displayed for the spatial memory load.

Method

Participants. Thirty-six Introductory Psychology students (ages 18–22 years) participated, from the same participant pool as Experiment 1. Eighteen performed the Simon task while holding a verbal memory load, and the other 18 performed the Simon task while holding a spatial memory load. I obtained informed consent at the beginning of the experiment, and credit was given at the end.

Materials and procedure. The experiment was similar to Experiment 1, except as noted. During the experiment, participants responded by pressing one of four keys on the keyboard. They placed their index fingers on the "Q" and "O" keys, as in Experiment 1, for responses in the Simon task, and their middle fingers on the "1" and "0" keys, located diagonally in the row above, for responses in the memory task. For the spatial memory load, the stimuli were four white squares that were randomly selected from nine possible positions in a 3 ×3 matrix. For the verbal memory load, the stimuli were four English letters that were randomly selected from nine possible letters. These letters were on a horizontal row at the center of the display.

The participant was instructed to remember either the squares' locations or the identities of the letters for a memory test that would occur after the choice-reaction task. Example trial sequences are shown in Figure 4.

For the spatial memory condition, a fixation was shown for 600 ms. After this time, four white squares were presented for 2,000 ms, and the participant

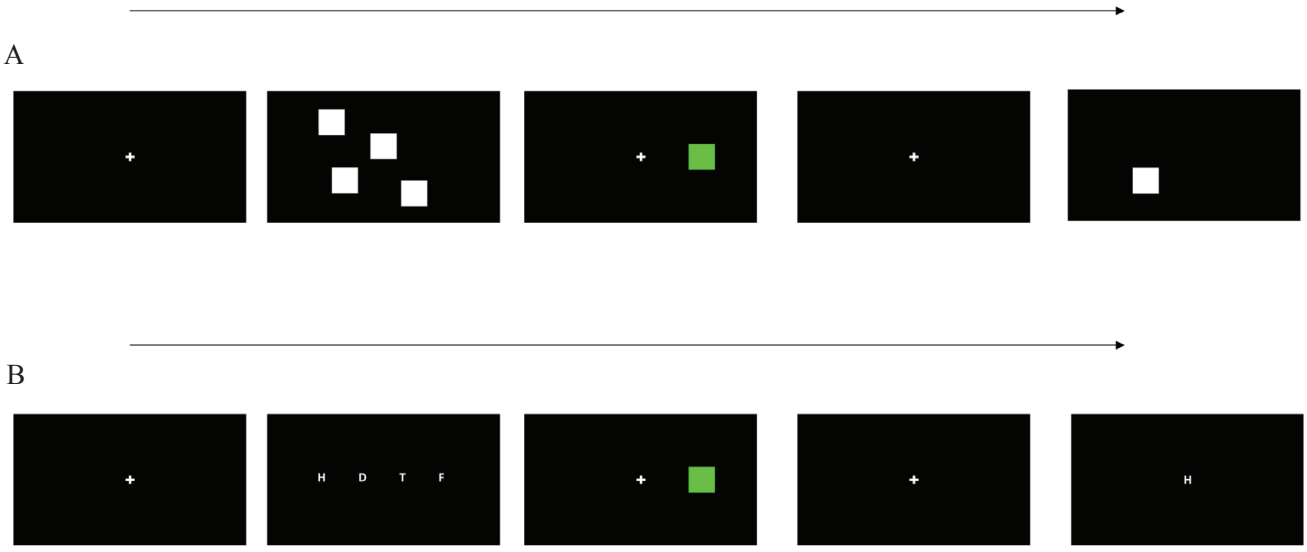

Figure 4. (A) Sequence of displays for spatial task in Experiment 2; (B) Sequence of displays for verbal task in Experiment 2.

memorized the locations. Following another fixation, the Simon task began, and the participant had to indicate the color of the stimulus by pressing "Q" or "O," as in Experiment 1. Lastly, the memory test was given, and the participant had to indicate whether a square shown was in the group shown prior to the Simon task by pressing the "1" key for yes or the "0" key for no.

For the verbal memory condition, a fixation was shown after instructions were given followed by four randomly assigned letters for 2,000 ms. Following another fixation, the Simon task began, in which the participant indicated whether the color was red or green by pressing "Q" or "O." Finally, in the memory test the participant had to indicate whether the letter presented was part of the group shown at the beginning of the trial.

Design. The spatial and verbal working memory loads were manipulated between subjects, and compatibility was manipulated within subjects. The experiment included one practice block of 12 trials and two experimental blocks of 96 trials.

Results and Discussion

For both conditions, RTs shorter than 250 ms or longer than 2,500 ms were eliminated from analyses (.002% of trials) and only correct responses were analyzed. The Simon task results showed longer RTs in both conditions (spatial, 847 ms; verbal; 652 ms) than found without a memory load (450 ms) in Experiment 1. The Simon effect was not significant overall [$F(1,18) = .100$, $p = .754$], but it tended to interact with the type of memory task [$F(1,18) = 2.61$, $p = .115$, $\eta^2 = .07$]. The Simon effect tended to reverse in the spatial memory load condition (-7 ms, $F = .377$, $p = .547$; see Figure 5) but to increase in the verbal memory load condition (18 ms, $F = 2.88$, $p = .108$; see Figure 5). The mean RT was 663 ms for congruent trials and 681 ms for incongruent trials.

The percentage errors for this experiment were low, being 0.9% for the congruent condition and 1.1% for the incongruent condition) [Spatial: $F = 0.42$ [Verbal: $F = .109$. The complete error data are shown in Table 1.

In this experiment, the Simon effect was eliminated during the spatial memory task. It appeared to increase slightly during the verbal memory task, compared to Experiment 1, and it definitely did not increase. A possible reason why the Simon effect was eliminated when the spatial load was added is exertion. Looking at the increase of RTs compared to Experiment 1, we can determine that having the

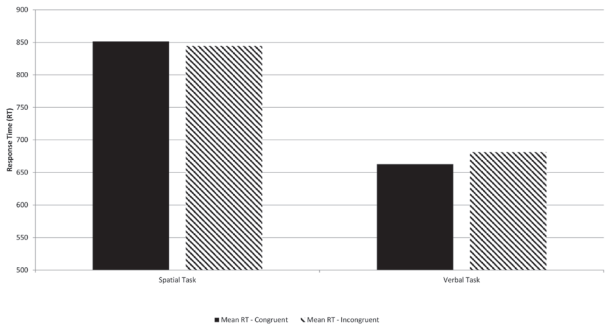

Figure 5. Congruent and incongruent mean reaction times for the spatial and verbal task.

	Response Times			Percent Errors		
	Simon	Spatial WM	Verbal WM	Simon	Spatial WM	Verbal WM
Congruent	445	851	663	.017	.009	.009
Incongruent	455	844	681	.019	.009	.012
Simon effect	10*	−7	18	.002	.000	.003

Note—WM: working memory. *$p < .05$

Table 1. Mean response times (in milliseconds), percentage of errors, and Simon effects for Experiments 1 (Simon alone) and 2 (Simon in the context of spatial WM or verbal WM).

participant remember spatial locations while answering quickly and accurately for the choice-reaction task made the Simon task more difficult overall. The same could be said about the verbal load because the experiment interacted with both spatial (choice-reaction task) and verbal memory, but the increase in RT was much less than with the spatial memory load. The verbal task did not prevent processing of stimulus position, and it may have increased its effect on performance. If so, this would suggest that the verbal load interfered with inhibition of the spatial activation, which is likely needed to select the correct response for the Simon task on incongruent trials (Ettinger et al., 2017). In conclusion, these results suggest that the Simon effect is dependent on both spatial and verbal working memory. It should be noted, though, that this pattern is opposite that of Zhao et al. (2010), who found the Simon task to be unaffected by the spatial load but eliminated by the verbal load.

GENERAL DISCUSSION

The results from Experiment 1 showed a significant Simon effect when the Simon task was performed alone. After obtaining those results, in Experiment 2 memory loads were incorporated to test whether irrelevant information would influence the Simon effect in a way similar to that in Zhao et al.'s (2010) study. The spatial memory task was chosen because when doing the Simon task, spatial coding takes place to respond to the stimuli. The verbal memory task was chosen because when doing the Simon task, nonspatial stimulus properties must be processed to respond accurately to the relevant stimulus dimension. The Simon effect was absent in the spatial memory load condition but present in the verbal memory load condition, possibly at an increased size.

The results of the present study are contradictory to those found by Zhao et al. (2010), for which the Simon effect was uninfluenced by a spatial memory and eliminated with a verbal memory load. An explanation of this difference could lie in the participants and stimuli used in the study. The participants in Zhao et al.'s study were Chinese and received Chinese characters during the verbal task. In contrast, the participants in this study were mostly American and all, regardless of their native language, received English letters to memorize during the verbal task. One factor related to these differences is that reading Chinese characters relies relatively more on visual cognitive processes than on phonological cognitive processes than does reading alphabetic English words (Tavassoli, 2002).

In addition, it is important to note that Zhao et al. (2010) gave their participants seven meaningful characters to memorize, whereas I gave participants only four random English letters with no specific meaning. Doing this could have reduced the memory load and made the verbal memory load less demanding. This would account for the appearance of the Simon effect in that condition of the present experiment. To test this hypothesis, the number of letters to memorize could be varied between four and seven, and words that have meaning could be used as stimuli. Of those variables, the size of the memory load is most likely to play a role because maintaining a representation of the instructed Simon task in working memory is essential.

However, the spatial task in the present study was a direct replication of Zhao et al.'s (2010) spatial condition. Consequently, it is not clear why my results for that condition differed from what they found. Again, the demographic differences between my participants and theirs could have been a contributing factor, but that does not seem likely since the task is nonverbal and should not be culturally dependent. Perhaps, though, remembering spatial positions was less difficult for the Chinese participants than for the participants in the present study, which could explain the lack of influence on the Simon effect in Zhao et al.'s study.

In total, my results and those of Zhao et al. (2010) suggest that the coding of stimulus location in Simon task is dependent on working memory, with high memory load tending to disrupt the coding regardless of whether the load is spatial or verbal.

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