**The Simon Effect as a Function of Temporal Overlap between Relevant and Irrelevant**

Leslie Ann Drummond
Faculty Sponsor: Dr. Debbie Wang

**Stimulus Information**

The Simon effect refers to an advantage in performance in a reaction time task when stimulus location corresponds to that of its response location even though the location of the stimulus is irrelevant. For example, if red or green color squares are presented randomly to the left or the right side, participants might be instructed to make a left response for the red square and right response for the green square. Reaction time is faster when the red square is presented on the left rather than on the right, and vice versa for the green square.

The effect was discovered by J.R. Simon (Simon & Small, 1969). Participants were told to respond to high and low pitch tones with their left and right hands. The tones were played in either the right or left ear which resulted in 60ms faster reaction times when the response location matched the tone location. The effect is now attributed to spatial coding of the stimulus and response. It is assumed that when a stimulus is presented, a code is automatically activated for the corresponding response. This activation facilitates the act of responding for consistent trials and interferes on inconsistent trials.

The specific reference frames relative to which the stimulus and response are coded is very important for the coding account. However, there are multiple reference frames available to code the locations of a stimulus and a response (Lamberts, Tavernier, & d'Ydewalle, 1992; Umiltà & Liotti, 1987). For example, location can be coded with reference to the midline of the body (subject-centered) or in relative position with respect to the other possible stimulus locations (stimulus-centered).

Umiltà & Liotti (1987, Experiments 3 and 4) tested the Simon effect using two types of reference frames to code the position of the stimulus. The stimulus was a square or a rectangle, presented in one of two boxes displayed in the left or right side (with respect to the body midline). The stimulus could be defined with respect to two frames: one frame was termed "side" which refers to position of the stimulus with the body as a reference point, and the other "relative position" which refers to position within the side in relation to another stimulus. These two codes result in four possible locations for a stimulus to appear: left side, left relative position; left side, right relative position; right side, left relative position; and right side, right relative position.

In Experiment 3, the screen was split into left visual field and right visual field via a fixation cross at the center. On one side of that point, two boxes appeared – one held the stimulus (a square or a rectangle) and the other was to determine relative location. Participants were told to respond to the shape of the stimulus. In half the trials, there was a 500ms delay after the boxes and before the stimulus appeared. In the other half, the boxes and the stimulus appeared together. Participants did not know in which relative position the stimulus would appear in. The main effect of delay was significant (overall reaction time was 71ms faster with a delay), and it interacted with relative position and response position to produce a 21ms Simon effect with the delay of the stimulus, whereas without the delay there was no effect. However, the interaction of side and response position was not significant, which indicated the absence of the correspondence effect for side and response location. The authors suggested that because side was pre-cued, the code for it was complete before the stimulus appeared, and therefore before the response code was formed.

In Experiment 4, the screen was once again split in half by the fixation cross. Four boxes appeared simultaneously – two were solid and two had a dotted outline. One of each type of box appeared in the left and right visual fields. This way, the participants did not know which visual field the stimulus would be presented in. The stimulus (a square or a rectangle) only appeared in the solid boxes, while the others marked relative position. Again, reaction time was 71ms faster with the delay than without and stimuli closest to the fixation point were responded to faster (20ms), showing a significant interaction between side and relative position. As with Experiment 3, there was a three-way interaction between delay, side, and relative position. This interaction resulted in a compatibility effect of 21ms with the delay, and no effect without it.

Both visual field and relative position were pre-cued in Experiment 5. There was no Simon effect in both the delay and the no delay condition. The authors theorized that this occurred because the irrelevant information was already processed before the stimulus and response codes were activated. Therefore, there was no significant difference in the reaction times of consistent and inconsistent trials.

Lamberts, Tavernier, & d'Ydewalle (1992) conducted an experiment similar to those of Umiltà and Liotti (1987) except for a few differences. First, the stimuli were a circle and a square instead of a square and a rectangle. Second, there were three reference frames, resulting in eight possible stimulus locations: hemispace (left or right of entire screen), visual hemifield within hemispace (left or right of either half of screen), and relative position within hemifield (left or right of the hemifield). Hemispace was always pre-cued because without it, the task of determining which hemifield the stimulus was in would be very difficult for participants and possibly confound the results.

In Experiment 2, a fixation point first appeared to pre-cue hemispace, and then -- much like Umiltà and Liotti's study -- two boxes were presented on one side of the fixation point (in the left or right hemifield), one of which contained the stimulus (a circle or a square in this case). Participants were told to respond to shape while location was irrelevant. The experiment resulted in three Simon effects: hemispace and response; hemifield and response; and relative position and response.

Participants in both of the two previously mentioned studies used several different reference frames to code the stimulus, but it is clear that the results are conflicting. Umilta and Liotti found no Simon effect when there were more than two possible locations for the stimulus to appear. When one of the spatial reference frames was pre-cued, the Simon effect occurred in the one that had not been pre-cued. However, Lamberts, Tavernier, and d'Ydewalle found a Simon effect for the pre-cued frame of Hemispace. A possible explanation for this unexpected result is that the participants were aware the different spatial codes could interfere with each other, and but did not intentionally suppress the code for Hemispace because it was an irrelevant feature (Lamberts, Tavernier, & d'Ydewalle 1992).

An alternative explanation for the conflicting results was presented by Hommel, who accounted for the difference in terms of stimulus complexity (1994). Umiltà and Liotti's study required the difficult task of discriminating between a square and a rectangle within another square. Comparatively, the study by Lamberts et. al was very easy, as we see by the 120ms faster reaction times (Hommel 1994). When the difficulty of the stimulus delays the processing of the relevant information, then the location code is not activated effectively and no Simon effect is present. Due to the fact that there was less temporal overlap involved because the code decayed, the Simon effect disappeared. Hommel compared an easy task (red and green) to a more difficult one (square and rectangle). The results showed that participants responded 48ms faster in the color condition and a Simon effect was produced for the colors but not the shapes. The "temporal lag" is longer for shapes, so the irrelevant location information decays while the relevant information is processed and therefore it is not available to interfere when the response code is activated (Hommel 1994). This is possibly intentional on the part of the participant, or it could be a by-product of the difficulty of the task.

Stimulus location is not the only feature that can be coded in multiple ways: response location also can be defined with respect to perceived action effects of multiple response features. For example, a simple key-press response that turns on a light can be interpreted as the action of pressing a key or the effect of turning on a light in response to a particular stimulus.

Hommel (1993b) obtained opposite Simon effects by describing the same response action with two different response features (the action or its effect). In Experiment 1, subjects responded to a high or low pitch tone by pressing a left or right key, which also resulted in a left or right light being turned on. The lights were inconsistently mapped with the response, meaning if the left key was pressed, the right light would be turned on; if the right key was pressed, the left light would be turned on. One group of subjects was instructed to turn on the lights (light-instruction), while the other group was instructed to press the keys (key-instruction) in response to the tones. The key-instruction group showed a tone-key Simon effect, with shorter reaction time when the tone location corresponded to the key location than when it did not. The light-instruction group showed a tone-light Simon effect, again with shorter reaction time when the tone location corresponded to the light location than when it did not. Since the light and key locations were opposite to each other, the direction of Simon effect was opposite for the two groups.

Hommel's (1993b) Experiment 2 reported evidence that other uninstructed features (i.e., keys and hands) played roles in the size of the Simon effect during the execution of the defined action (i.e., turning on the light). When the spatial code of an uninstructed action effect (produced by the uninstructed response feature) and the spatial code of the stimulus corresponded, a facilitation effect was found. When the spatial code of an uninstructed feature and the spatial code of a stimulus did not correspond, interference was found. Because the Simon effect did not disappear and the direction of the Simon effect corresponded to the instructed action effect, Hommel concluded that intended action goal (in terms of the instructed action) determines the direction of the Simon effect and other non-intended effects attributed additively to the size of the Simon effect. The idea that post-action effects can influence performance was further confirmed by recent studies (Grosjean & Mordkoff, 2002; Wang, Proctor, & Pick, 2007).

Hommel (1996, 1997) proposed the action-concept model in which he explained why irrelevant information that occurs after a stimulus and response still affects reaction time. The model states that consequences of a response (action effect) can be coded in an action concept and thus can participate in the response selection process. Participants were asked to complete an original Simon task, with irrelevant post-response stimuli added – in the form of rising tones and a fixation cross – in an attempt to increase the Simon effect. Same side, opposite side, and neutral stimuli had only been used before in Hommel's work. Results supported their hypothesis that the action effects would become associated with responses. The Simon effect was increased by 17ms with same side stimuli, and decreased by 7ms with opposite side stimuli.

The Simon effect has also been demonstrated to extend beyond spatial tasks-In Hommel's (1996) Experiment 4, participants were instructed to respond to the color (red or green) of the stimulus. Instead of two separate keys, responses were made by pressing the same key once or twice. Responses were paired with an action-effect tone (200 or 500Hz tone), which was either consistent or inconsistent with an inducing tone that was randomly selected to play with the appearance of the stimulus. There was no compatibility effect on this task. Hommel suggested this could be due to the lack of temporal overlap between the relevant and irrelevant stimulus processing. In other words, the relatively simple task of telling apart red and green allowed for fast processing and therefore the irrelevant information had no time to have an effect.

In Experiment 5a, the difficulty of the color task was-increased. All aspects were the same as those in Experiment 4, except the stimuli were reddish-purple and bluish-purple rectangles, and they were presented for 1000ms instead of 120ms. Reaction time increased 70-80ms overall, and a Simon effect was produced. This fits with the temporal overlap theory in that when the relevant information took longer to process, the irrelevant information overlapped it and created a Simon effect.

The temporal overlap theory suggests that less complex stimuli will result in no overlapping of irrelevant and irrelevant stimulus processing and therefore no Simon effect will occur. Previous research indicates that the size of the Simon effect varies depends on the task. We suspect that the size of the Simon effect might be changed as a function of the temporal overlap between the relevant and irrelevant stimulus information. To test this hypothesis, we need to manipulate the duration of the overlap between irrelevant and relevant stimulus processing. This is achieved by manipulating the complexity of the stimulus. Two experiments were conducted to test the influence of the temporal overlap on the size of the Simon effect.

**Experiment 1**

According to the Temporal Overlap theory, if there is no overlap of irrelevant information (consistent or inconsistent tones) onto relevant information (color of the stimulus), the irrelevant information will not affect the processing of relevant information and there will not be a Simon effect.

**Method**

*Participants*

Forty undergraduate students at the University of North Florida participated in the study to obtain extra credit in Psychology courses. There were 29 females and 11 males, aged 18 to 50 years.

*Apparatus and Stimuli*

The experiment was designed in ePrime software. A Dell Optiplex SX280 computer with keyboard was used to display the visual stimuli. Tones were heard from Panasonic RP-HT355 stereo headphones. Responses were made with an Apple M7697ZM Optical Pro Mouse with only one button. Stimuli were created by changing the red, green, and blue registers in a RGB color system which the range of each primary color can be set between 0-255.  If the red primary color is set at 255 and others are set to 0, it would show pure red, the same for the other two primary color. The stimuli we used are displayed in Table 1.

Table 1.1 - Experiment 1 Stimulus Colors

| Color 1 (R255, G0, B0) | Color 2 (R0, G255, B0) |
|---|---|
| | |

*Procedure*

Participants were seated in a well-lit lab. Instructions appeared on the screen, displaying the colors that would appear and stating the participant was to press the mouse once or twice depending on the color of the stimulus. They were also notified that they would hear tones and those should be ignored because they had no relevance to the task. The mouse was secured to the desk at the middle of the computer screen to eliminate spatial characteristics. Participants pressed the space bar when they were ready to begin.

In the 48 practice trials, an asterisk appeared as the fixation point in the center of the screen for 500ms. A red or a green rectangle (1.0 x 1.8cm) was then presented in the center of the screen for 120ms. Half of the participants were instructed to click once for the red stimulus and twice for the green; the other half assigned the opposite mapping to balance the order effect. Immediately following a response to the stimulus, a 50ms tone (the action-effect) sounded through both headphones. The tone was either low (200Hz) or high (500Hz) and each was paired with the same response (1 or 2 clicks of the mouse) throughout the experiment. If no response was made in 1000ms, the screen flashed “No Response Detected!” before beginning the next trial.

Upon completion of the practice session, a second instruction screen appeared. The participants were informed that they would now hear two 50ms tones instead of one; however, the tones were still irrelevant to the task of identifying the stimulus. The fixation point, stimuli, and timing were all identical to the practice trials. The first tone sounded as soon as the stimulus appeared (inducing), and the second tone sounded as soon as a response was made (action-effect). The action-effect tone was therefore coded as consistent or inconsistent in terms of the inducing tone. Participants completed 100 test trials.

The design resulted in four conditions, with 10 participants per condition. The stimulus and inducing tones were randomized within groups; while the response and action-effect tones were randomized between groups (see Table 1.2).

Table 1.2 – Experiment 1 conditions

| Block ID# | Stimulus | Inducing | Response | Action-effect | C/IC |
|---|---|---|---|---|---|
| 1<br>1 | Red | Low | 1 | High | IC |
| 1 | Red | High | 1 | High | C |
| 1 | Green | Low | 2 | Low | C |

| | | | | | |
|---|---|---|---|---|---|
| 1 | Green | High | 2 | Low | IC |
| 2 | Red | Low | 2 | Low | C |
| 2 | Red | High | 2 | Low | IC |
| 2 | Green | Low | 1 | High | IC |
| 2 | Green | High | 1 | High | C |
| 3 | Red | Low | 1 | Low | C |
| 3 | Red | High | 1 | Low | IC |
| 3 | Green | Low | 2 | High | IC |
| 3 | Green | High | 2 | High | C |
| 4 | Red | Low | 2 | High | IC |
| 4 | Red | High | 2 | High | C |
| 4 | Green | Low | 1 | Low | C |
| 4 | Green | High | 1 | Low | IC |

**Results**

Incorrect responses and anticipations (.52%) were not included in the analyses. Participants with less than 93% accuracy were not analyzed. Results of a repeated measure t-test indicated that there was no significant difference in the reaction times on Consistent (*M*=235.21ms) and Inconsistent trials (*M*=238ms), $t(38) = -1.044$, $p = .303$. There was also no interaction between Mapping and Block ID ($p = .061$) nor between Mapping and Sex ($p = .481$).

**Discussion**

There was no correspondence effect between the inducing tone and the action-effect tone. This result is consistent with Hommel's (1996) result. According to the temporal overlap model: in this experiment, the stimuli were easily to be identified, and the absence of the correspondence effect is due to the fact that relevant stimulus (color pair) was identified earlier than the inducing tone, so that response would have been selected before the inducing tone started to produce an effect. Also this theory predicts that as the relevant task becomes harder, and the relevant stimuli take longer time to be identified. Consequently, the irrelevant information (the inducing tone) would be no longer too late to produce an effect on the response selection. Thus, in Experiment 2, we increased the complexity of the stimulus, and predicted that the correspondence effect would be present.

**Experiment 2**

The purpose of the second experiment is to evaluate how the correspondence effect would change as a function of temporal overlap by manipulating the complexity of the relevant stimuli. Seven color pairs (one pure blue and one with increasing amounts of red hue) were created of increasing difficulty. According to Temporal Ovelap theory, as the stimulus complexity increases there will be a bigger overlap of irrelevant information onto relevant information and therefore a Simon effect.

**Method**

*Participants*

20 undergraduate students at the University of North Florida participated in the study to obtain extra credit in Psychology courses. There were 14 females and 6 males, aged 18 to 51 years.

*Apparatus and Stimuli*

The experiment was designed in ePrime software. A Dell Optiplex SX280 computer with keyboard was used to display the visual stimuli. Tones were heard from Panasonic RP-HT355 stereo headphones. Responses were made with an Apple M7697ZM Optical Pro Mouse with only one button. Stimuli were created using the same method as Experiment 1. Perceptually, the colors display a spectrum of small changes in between each (see Table 2.1).

Table 2.1 – Experiment 2 Stimulus Colors

| Pair # | Color 1 | Color 2 |
|---|---|---|
| Control | R0, G0, B255 | R255, G0, B255 |

| | | |
|---|---|---|
| Pair 7 | R0, G0, B255 | R180, G0, B255 |
| Pair 6 | R0, G0, B255 | R160, G0, B255 |
| Pair 5 | R0, G0, B255 | R140, G0, B255 |
| Pair 4 | R0, G0, B255 | R105, G0, B255 |
| Pair 3 | R0, G0, B255 | R90, G0, B255 |
| Pair 2 | R0, G0, B255 | R55, G0, B255 |

*Procedure*

The task for Experiment 2 was to discriminate between a pure blue shade and one of six others, including a pure purple shade which served as the Control condition (see Table 2.1). In order to make the task more difficult, stimuli were only presented for 120ms instead of the 1000ms used by Hommel (1994). These seven color pairs were each present for 20 practice trials and 80 test trials. The Control condition was always the first, while the other six were randomized. All participants experienced all seven pairs.

Before the practice session, the experimenter determined if the participant could see the difference between the two colors. Participants were again notified that they would hear tones and should ignore them because they had no relevance to the task. The experimenter pressed the 'L' key when the participant was ready to begin. The same procedure was repeated for all seven color pairs. All other specifications of the experiment were the same as Experiment 1.

**Results**

A 2 (mapping) x 7 (block) ANOVA was performed on reaction time. There was no significant difference in reaction time between Consistent and Inconsistent trials for any of the 7 conditions (see Table 2.2), nor was there an interaction between mapping and blocks. Using the location of the most difficult block as a covariate did not show any significant effects, but it may have been a factor in the wide participant variability. However, the ANOVA did indicate that the effect of Color Difficulty was significant, $F(1,19) = 12.048$, $p = .003$. As the color pairs became harder to tell apart, reaction time increased significantly. By comparing the $SD_{pooled}$, we see a much bigger variance in the reaction times of the two most difficult pairs. This shows a trend in the direction we initially hypothesized.

Table 2.2 - All Pairs RT, Simon effect, and Std. Deviation

| Pair | Cons RT | Incons RT | IC - C | $SD_{pooled}$ | Std. Deviation |
|---|---|---|---|---|---|
| Control | 212 | 219 | 7 | .173 | 40.46 |
| Pair 7 | 220 | 228 | 8 | .164 | 48.71 |
| Pair 6 | 219 | 222 | 3 | .060 | 49.75 |
| Pair 5 | 225 | 218 | -7 | -.128 | 54.72 |
| Pair 4 | 235 | 245 | 10 | .1567 | 63.77 |
| Pair 3 | 236 | 268 | 34 | .524 | 64.89 |
| Pair 2 | 258 | 289 | 31 | .414 | 74.89 |

**Discussion**

The results were certainly not expected, even though the correspondence effect tended to be smaller as the complexity decreased. According to Hommel's temporal overlap model, the absence of the Simon effect in Experiment 1 is due to the fact that relevant stimulus (color) was identified earlier than the irrelevant stimulus (inducing tone), so that it was too late for the tone to influence the response selection. However, as the complexity of the stimulus increased, the inducing tone should not have been too late to produce an effect on the response selection. We noticed that the reaction time for our studies was much faster than that of Hommel's (1996) Experiment 4 ($M$ = 313 ms) and 5a ($M$ = 462 ms). It is possible that our relevant stimulus was easier to be identified than his stimuli. While he used a reddish-purple and a bluish-purple color, we always used a pure blue shade and paired it with another that slowly increased to pure purple. While the Consistent mapping produced faster reaction time in all the conditions (except for Pair 5), none of the amounts was significant. It seems that the stimulus was still being processed before the irrelevant information (tones) had a chance to influence reaction time. Seven of the participants actually showed the reverse effect for all conditions except the Control. Five other participants only showed the reverse effect in the Control only. An alternative explanation for the absence of the correspondence effect is due to wide variability of each participant's reaction times.

**Conclusions**

The two experiments examined how the size of the correspondence effect varies as a function of the temporal overlap between the relevant and irrelevant task. According to the temporal overlap model, when there is an overlap of the relevant tasks and the irrelevant stimulus processing, a correspondence effect is expected. Otherwise, it is too late for the irrelevant stimulus to produce an effect. However, the influence of the duration of the overlap on the correspondence effect has not been addressed previously.

In Experiment 1, the results provided further evidence for the temporal overlap model which predicts that when a stimulus is easily identified, there is no correspondence effect due to the lack of overlap between the relevant and irrelevant task. However, when we increased the complexity of the relevant stimuli in Experiment 2 and in turn, made stimulus identification harder, reaction time increased but no correspondence effect was found. This could be due to the fact that our relevant stimuli were still identified before the inducing tone which is evident in the much faster reaction times of this study. Hommel (1996) generated the color pairs using DOS and an old-fashioned EGA screen model, where the three RGB color registers could be set to 0-63 (by personal communication), while we used a RGB system in Microsoft Word. Thus the color differences may not be equivalent. Another explanation would be individual differences between participants. We noticed that seven out of 20 participants showed larger standard deviation for the RT. To demonstrate this effect, it is better to run more trials for each participant in the future studies because the size of the correspondence effect still suggests that it was decreasing as the complexity decreased.

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