BACHELOR THESIS

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The development of the Simon effect when automating keying sequences

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Abstract An experimental investigation was conducted to determine the impact of the Simon effect on the performance of the discrete sequence production task. During the experiment, we had 16 participants practice two seven-key sequences by pressing four keys corresponding to four letters that appeared within one of four placeholders on a screen in a predetermined order. In order to explore the development of the Simon effect the letters were presented at congruent and incongruent letter locations. Results indicate that reaction times and error proportions decrease over practice due to motor chunk development and that the Simon effect causes significantly longer reaction times and higher error proportions. At the end of the practice phase a test block was implemented in which two unfamiliar sequences were introduced. Results showed that the Simon effect caused lower reaction times and error proportions at familiar sequences. Although the Simon effect remains present overall, it was indicated that the effect on some individual responses may vanish. This work provides noteworthy contributions to the field of discrete sequence production and might contribute to the ongoing debate on the mechanisms underlying the Simon effect.

Keywords Cognitive models · Discrete keying sequence · Sequence learning · Motor chunking · Simon effect

Introduction

The curious observation J. Richard Simon (1967) described as an "*innate tendency to respond toward the source of stimulation*" is called the Simon effect nowadays and turned out to become a window into important aspects of human cognition and action over the last 50 years (Hommel, 2011; Lubbe, 2011). In an experimental series in 1990, for example, participants had to make a right-handed response whenever a circle appeared on a display and a left-handed response when a square did. Although the position of the stimulus was irrelevant, reaction times were significantly faster when the object appeared on the same side as the required response (Simon, 1990). Gaining insights into the factors that affect the speed of translating information from a display to a control action is crucial for cognitive psychologists and human factors engineers and has important safety implications in industrial design (Simon, 1990; Smith & Kosslyn, 2013).

Another fundamental topic that was studied extensively within the last half-century was the ability to sequence action and how it progresses over practice and time (Lashley, 1951; Abrahamse et al., 2010). Automated movement sequences enable humans to perform actions from tying the shoestrings to shifting gears when driving a car in a hectic city (Abrahamse et al., 2010; Abrahamse et al., 2013, Verwey et al., 2015). In his article "The Problem of Serial Order in Behavior" Karl Lashley (1951) concludes that activity consists of structured patterns of activity with an underlying hierarchical structure. To find evidence for this theory on hierarchically controlled execution, Rosenbaum et al. (1983) let subjects perform memorized sequences of finger responses like those used in playing the piano. Strong support for a hierarchical execution model was found. In other words, action sequences can consist of subsequences.

George Miller (1956) coined the term *chunk*, which refers to the largest meaningful unit of information a person recognizes. In his one-dimensional absolute-judgement task, 10 tones, varying in pitch, were presented to the participants and they were asked to react to each stimulus with a corresponding response. The study showed that the performance was nearly perfect but declined when more than five or six different stimuli were added. The phenomenon of *chunking* can also be observed in motoric movement where a given number of individual movements are bound in a fluid, uniform movement, called *motor chunk* (Halford et al., 1998; Wymbs et al., 2012). This separation of a whole movement into subsequences reduces the memory load while executing a continuing performance (Bo and Seidler, 2009; Ericsson et al., 1980). In his studies on pigeons, monkeys and humans, Terrace (2001) identified *chunks* in motor learning by pauses between successive actions.

Motor sequence learning is described as "the acquisition of the skill to rapidly and accurately produce a sequence of movements with limited effort and/or attentional monitoring" and is usually based on repetitive practice and explicit instruction (Abrahamse et al., 2013). To study the cognitive processes and representations underlying automated movement sequences in humans, researchers have developed several laboratory tasks, among others the *discrete sequence production* (DSP) task (Abrahamse et al. 2013; Verwey et al. 2015).

At the beginning of the DSP task, participants are asked to place four to eight fingers on the designated keys of the keyboard (e.g. C, V, B, N). A number of placeholders (typically squares) that is consistent to the number of keys is aligned on the screen. Participants are told to press a particular key (e.g. B) whenever the corresponding placeholder lights up (in this case the third of four placeholders). After the key press, the next stimulus appears. Usually, a sequence is conducted that consists of two fixed series of 3-7 stimuli (e.g. V, N, B, N, V, B, C). The *motor chunks* then develop during the practice phase, which includes 500 – 1000 repetitions per sequence (Abrahamse et al., 2013). During the following phase a new sequence is introduced that is used as a control condition to study the previously developed *motor chunks*.

According to the *dual processor model* participants go through three different stages of sequence execution (Abrahamse et al., 2013). At first, when unfamiliar sequences are presented, the stimulus (placeholder lighting up) is processed by the *cognitive processor* based on stimulus-response reaction. The *cognitive processor* then triggers the *motor processor* to react to a stimulus by executing the response. This is called the *reaction mode*. During *associative mode*, the *cognitive processor* develops a weak sequence representation. When this representation gets stronger, *motor chunks* develop, allowing the *chunking mode* (Abrahamse et al., 2013). The *chunks* are loaded into the *motor buffer*. When the chunk is loaded into the *motor buffer*, the *cognitive processor* triggers the *motor processor* to read the *chunk* and execute it fairly autonomously as if it was a single response (Abrahamse et al., 2013).

The present study

During the present study, an adjusted version of the DSP was used. In the first block, four letters (E, U, R, O) corresponding to four specific keypresses (C, V, B, N) are presented on a central position of the screen in order to make the participants familiar with the letter-key-mapping. In the following practice blocks 2-6, four placeholders are aligned on the screen according to the usual DSP task set-up. Two sequences, each consisting of seven keys (e. g. V, N, B, N, V, B, C) are now presented by these four placeholders. As there is strong evidence that *motor chunks* will develop during this phase, the first hypothesis is stated as follows: Performance of the participants on the DSP task increases due to motor chunk development (1).

However, to induce the Simon effect, stimuli presented within the placeholders will be at congruent and incongruent locations, mixed within each sequence. A difference in reaction times is expected to appear when location and reaction on the stimuli are incongruent. Moreover, reaction times on manipulated stimuli within the DSP task are expected to be longer in the beginning. Therefore the second hypothesis states that the Simon effect causes significantly longer reaction times on stimuli with incongruent locations when participants begin with learning the keying sequences (2).

When participants become skilled at the automated keying sequences they will recall and execute the fixed series. Stimuli indicating later responses in the sequence are expected to be ignored as the sequences become *chunks*. Also, *attentional orienting* within a *chunk* is not expected to occur. Therefore, the Simon effect is expected to become less important and finally disappears over time. This leads to the third hypothesis: The impact of the Simon effect vanishes when participants become skilled in the automated keying sequences (3).

After the practice blocks, the test phase (block 7) is implemented. During this block, unfamiliar sequences are implemented to check whether the previously expected reduction of the Simon effect is sequence or task-specific. Additionally, the familiar sequences are repeated. Both, unfamiliar and familiar sequences are presented within one placeholder, similar to the first block, and within one of four placeholders, similar to blocks 2-6. During this practice block, the Simon effect is expected to stay eliminated in the familiar sequences but occurs again in the unfamiliar sequences. The fourth hypothesis states: The Simon effect increases again within the unfamiliar sequences but does not reappear within the familiar sequences (4).

Method

Participants

Thirty-two students (21 female, M age = 22 years, SD = 3 years) from the University of Twente, the Saxion University and the Academy of Pop Music and

MediaMusic took part in this study in exchange for course credit or participant fee (12€). Informed consent was obtained from all individual participants included in the study. The study had been approved by the Ethics Committee of the University of Twente and was performed in accordance with the ethical standards described in the Declaration of Helsinki.

Apparatus

The experiment was programmed and conducted in E-Prime 2.0 running under Windows 7. Instructions and Stimuli were presented on a 15″ CRT display at a refresh rate of 75 Hz, with a resolution of 640 × 480 pixels, and at 16-bit color depth.

USB keyboard and mouse were used as input devices. Participants used the keys C, V, B and N to react to stimuli and "space" to continue to the next screen when reading the instructions. The mouse was used solely to select answers during the awareness task. Other keys and buttons were disabled. The room (2.25 × 2.25 × 3.50 m) was dimly lit with fluorescent light and fitted with a webcam for monitoring purposes.

Task

At the beginning of the experiment, participants were instructed to place their left middle and index fingers on the keys C and V, respectively, and the right index and middle finger on the keys B and N. The first block was conducted in order to familiarize the participants with the letter-key mapping. During this block, one square was aligned in the center of the screen as a placeholder. Two 7-element sequences consisting of the letters E, U, R, O appeared within this square and participants were asked to react to the letters by pressing the corresponding keys C, V, B, N. During the first out of the two sub-blocks, E U R O was presented underneath the square to make orientation easier for the participants.

During the practice blocks 2-6, four squares were aligned in a row. The letters were then presented at a congruent or incongruent location, mixed within each sequence. Participants were instructed to ignore the letter location and not told about the sequence order.

A pool of four different 7-element sequences was designed (sequences A-D) and participants were chosen to practice two of these sequences while the other two sequences were used as control condition later on. Thus, participants were practicing sequence A and B, sequence B and C, sequence C and D or sequence D and A depending on the participant number. Furthermore the proportion of congruent and incongruent stimuli was manipulated and participants were assigned to one of two conditions also depending on the participant number. Even participant numbers (n=16) were assigned to the first condition with a proportion of 25% congruent and 75% incongruent letter positions while odd participant numbers (n=16) were assigned to the second condition with 50% congruent and 50% incongruent letter positions.

After block 6 the awareness task was conducted. A questionnaire, designed to analyze the knowledge participants gained about the sequences. The program asked for three different types of awareness, which appeared in a counterbalanced order. During the first type of question, four empty placeholders were aligned in a row corresponding to the four keys participants had to press during the practice blocks. The participants were asked to click on the squares in the same order as they had been pressing the keys previously. In the second type of question, four squares were aligned in a diamond shaped order. Within these squares, the four letters E, U, R and O were displayed. Participants were asked to click on the letters in the same order as they appeared during the practice blocks. In the third type of question, four squares were aligned similar to the second phase but this time the letters C, V, B and N were displayed. After every question, participants were asked to indicate the strategy they had been using to indicate the sequences. The options were (a) they remembered the order of the symbols on the keys, (b) they executed the sequences with their fingers on the table, (c) they executed the sequences in their mind, (d) they remembered the order of the stimulus locations, or (e) they had no idea about the sequences. Furthermore, participants were asked how confident they were about the order they indicated using a five point Likert scale ranging from very confident to very unconfident.

After the awareness task, block 7, the test phase, was conducted. During this block, participants had to react to the familiar sequences and to two unfamiliar sequences, the previously mentioned control condition. Furthermore, there were two conditions in which the sequences were presented. A balanced order determined which condition was conducted first. In one condition, sequences were displayed within the same letter location; during the other condition sequences were presented in one of the four placeholders, similar to blocks 2-6.

During the experiment reaction times were measured. Pressing a false key (i.e., failing to execute the sequence in its correct order) resulted in the message “Wrong key” (in Dutch) being displayed for 500 ms. The program than continued with the next letter of the given sequence.

Procedure

At the start of the experiment, participants were asked to take a seat in front of the computer. They were instructed that reaction times would be measured under different circumstances and that they had to react to the letters E, U, R and O by pressing C, V, B and N correspondingly. Participants were told that the experiment would last about two hours, they were asked to respond as fast as possible to the trials while not exceeding a 6% error rate. Also, participants were informed that participation was voluntary, that no risks were involved in participating, that the data collection would be anonymous and that they were filmed for monitoring purposes. Participants then signed the informed consent form while the experimenter wrote down the number and name of the participant, the date and the time of the day into the logbook. After that, the experimenter started the program, entered the number of the participant and the number of the block and left the room.

An onscreen message instructed participants on which keys they were to place their fingers. At the end of each block, and halfway through each block, participants received feedback, displaying their average reaction time and error rates.

The experiment consisted of 7 blocks in a single session. At first, the practice blocks 1 to 6 were conducted, each composed of an 50-trial sub-block, a 20-s break, and another 50-trial sub-block. At the end of each block, a message informed the participant that the block had finished and that a 3-min break started. After the break, the experimenter encouraged the participant to improve sequence execution if necessary and started the next block.

Across Blocks 1 to 6 participants performed 250 repetitions of each sequence. After block 6, the participants were asked to carry out the awareness test, a questionnaire about the two sequences they had been practicing. After completing the awareness test, the test phase, block 7, was conducted. This block was composed of four 2x25-trial sub-blocks with a 20-s break in the middle.

After participants completed block 7, the experimenter wrote down events into the logbook that could have had an impact on the experiment and granted the credits or participation fee.

Data analysis

The first two trials of each sub-block and sequences that were considered outliers were excluded from the RT analyses. Sequences were considered outliers when their total execution time was longer than the average time plus three times the standard deviation in a block. This excluded 2.7 % of the sequences. Reaction times were submitted to an ANOVA. Errors were computed per block and sequence, error frequency was arcsine-transformed to stabilize the variance and then also submitted to an ANOVA (p. 356 in Winer et al. 1991). Paired Sample T-Tests were conducted to individually compare the average reaction times on single keys between congruent and incongruent letter positions. Awareness task data was excluded from this analysis.

Results

Practice blocks

Figure 1 shows the RTs obtained with congruent and incongruent letter position across blocks 2-6 as a function of Block and Congruency across the two sequences. The RTs were analyzed using a 5 (Block) × 2 (Congruent vs Incongruent) × 7 (Key) repeated-measures ANOVA. This ANOVA showed main effects of Block, $F(4,60) = 58.94$, $p < .001$, Congruency, $F(1,15) = 50.54$, $p < .001$ and Key, $F(6,90) = 31.63$, $p < .001$. Furthermore, interaction effects were obtained on Block x Congruency, $F(4, 60) = 2.99$, $p <$

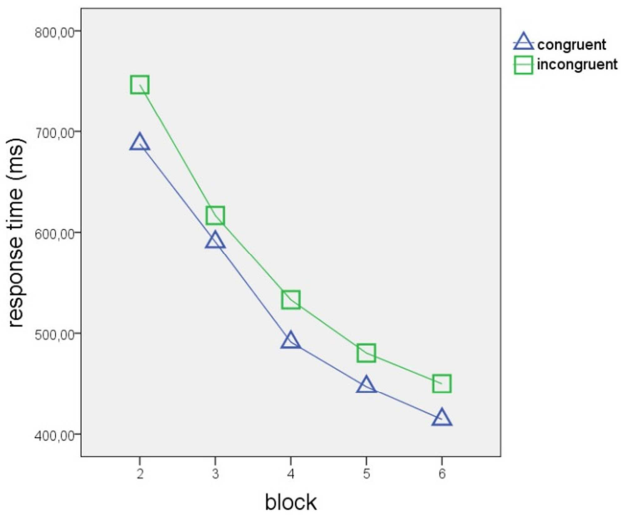

Fig. 1 Response times over blocks 2-6 on congruent and incongruent letter positions.

.026. Results of the Block x Key interaction, $F(24,360) = 6.1$, $p < .001$, support the notions that participants improved with practice in conditions with both, congruent and incongruent letter positions. Moreover, a Congruency × Key interaction confirmed that key presses at incongruent locations caused significantly longer reaction times than key presses at congruent locations, $F(6,90) = 7.28$, $p < .001$.

Estimated means of the error proportions showed a decrease from 3.5% to 2.7% errors from block 1 to block 2. Although the proportion stayed at 2.7% during block 3, it slightly increased to 2.8%, 3% and 3.3% during block 4, 5 and 6, respectively. The standard error was at .005 in block 1, dropped to .003 in block 2 and stayed at .003 except for a small increase to .004 during block 4 and 5. The overall error proportion was 2.2% for congruent and 3.9% for incongruent letter positions. Furthermore, standard error doubled from .002 to .004 at incongruent letter positions.

Arcsin-transformed error proportions were subjected to the same repeated-measures ANOVA as used for the RTs. However, Block 1 was also included resulting in a 6 (Block) × 2 (Congruent vs Incongruent) × 7 (Key) repeated-measures ANOVA. Again, ANOVA showed main effects of Block, $F(5,75) = 2.37$, $p < .047$, Congruency, $F(1,15) = 89.56$, $p < .001$ and Key, $F(6,90) = 4.84$, $p < .001$. Furthermore, interaction effects were found for Block x Key, $F(30,450) = 1.85$, $p < .005$ and Block x Congruency, $F(5,75) = 6.8$, $p < .001$. These results indicated that the error rate also decreases with practice in both conditions, congruent and incongruent.

A new 5 (Block) × 2 (Congruent vs Incongruent) × 7 (Key) repeated-measures ANOVA for arcsin-transformed Error proportions showed main effects of Congruency, $F(1,15) = 86.99$, $p < .001$, but no significant Congruency x Key interaction effect, $F(6,90) = 0.67$, $p < .676$, indicating that there are significant differences between the two congruency conditions but that individual differences vary between the seven keys.

Test block

Estimated means of the error proportions showed a 4.2% error proportion for unfamiliar sequences compared to 3.3% errors for familiar sequences. Similar differences were found for stimulus location with 4.1% errors on 4 stimulus locations and 3.4% errors on 1 stimulus location. All mentioned values had the same standard error of .004. In more detail, differences in error proportions between the two stimulus location conditions were higher in unfamiliar sequences than in familiar sequences. Results showed an increase from 3.7% errors (SE=.005) on 1 stimulus location to 4.7% errors (SE=.004) on 4 stimulus locations in unfamiliar sequences, whereas these error proportions increased from 3.1% (SE=.004) to 3.5% (SE=.005) when the sequences were familiar. Incongruent stimulus location raised the overall error proportion from 3.2% (SE=.003) to 4.3% (SE=.004).

Arcsin-transformed error proportions of block 7 were analyzed using a 2 (Unfamiliar vs. Familiar Sequences) × 2 (1 vs 4 Stimulus Locations) × 2 (Congruent vs Incongruent) × 7 (Key) repeated-measures ANOVA. Results showed main effects of Key, $F(6,90) = 3.02$, $p = .010$, Unfamiliar vs Familiar sequences, $F(1,15) = 9.19$, $p = .008$, and Congruency, $F(1,15) = 0.58$, $p = .004$ suggesting that both, unfamiliar sequences and incongruent letter position increased the error proportion. Furthermore, an interaction effect of Stimulus Location x Congruency, $F(1,15) = 6.94$, $p = .019$, was obtained.

To analyze the differences on reaction times between familiar and unfamiliar sequences the averages of the sequences were analyzed using the same 2 (Unfamiliar vs.

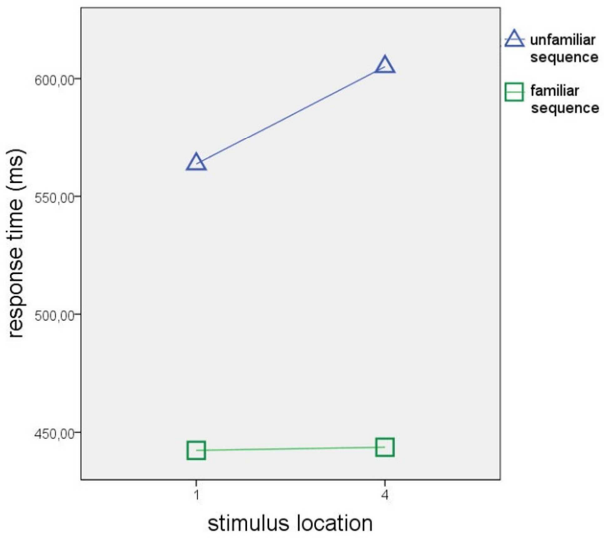

Fig. 2 Response time differences between 1 or 4 stimulus locations on familiar and unfamiliar sequences during block 7.

Familiar Sequences) × 2 (1 vs 4 Stimulus Locations) × 2 (Congruent vs Incongruent) × 7 (Key) repeated-measures ANOVA. Results showed significant main effects of Key, $F(6,90) = 45.11$, $p < .001$ and Unfamiliar vs. Familiar sequences, $F(1,15) = 22.39$, $p < .001$. Moreover, interaction effects of Unfamiliar vs. Familiar Sequences x Key, $F(6,90) = 2.41$, $p < .034$ were obtained. These results indicated that reaction times were longer during the unfamiliar sequences compared to the familiar sequences.

While interaction effects of Stimulus Location x Congruency, $F(1,15) = 12.37$, $p < .003$, were found, no significant main effects of Stimulus Location could be obtained. Figure 2 suggested that the stimulus location only affected reaction times during the unfamiliar sequences, whereas reaction times did not differ significantly through familiar sequences.

Furthermore, main effects of Congruency, $F(1,15) = 12.13$, $p < .003$, indicated that reaction times were overall influenced by the congruency of the letter location. However, the same ANOVA showed no significant interaction effects of Congruency x Key, $F(6,90) = 1.39$, $p < .228$. This result suggested that not all key presses at incongruent locations caused longer reaction times than key presses at congruent locations (see Fig. 3).

To further examine this assumption, paired sample T-tests were conducted to individually compare the average reaction times on every single key between congruent and incongruent letter positions during the familiar sequences in block 7. Significant differences were obtained only in the scores for Key 2, $T(15) = -3.66$, $p < .002$ and Key 5, $T(15) = -3.92$, $p < .001$. Both showed paired mean differences of 72.13 ms (SD=78.84) and 60.45 ms (SD=61.71), respectively. However, differences between the other pairs were not significant and varied between 14.77 ms (SD=71.05) and 38.94 ms (SD=106.84).

Taken together, these analyses showed several findings in support of the hypotheses: Both, reaction times and error proportions decreased over practice in accordance with the first hypothesis (see Fig. 1). During the practice blocks, reaction times were significantly longer and error proportions were higher when letters appeared on incongruent positions compared to reaction times and error rates on congruent letter positions as stated in the second hypothesis (see Fig. 1). During the test block, reaction times were overall shorter and error proportions were lower when participants were familiar with the sequences. Reaction times and error proportions of familiar sequences were also not affected by the number of stimulus locations, whereas both increased on unfamiliar sequences during the 4 stimulus location condition (see Fig. 2). These findings were in line with the third hypothesis. Contrary to the fourth hypothesis, results suggest that the congruency of the letter location still influenced both, unfamiliar and familiar sequences. However, paired sample t-tests on the familiar sequences suggested that only the second and the fifth key differed significantly in reaction times between congruent and incongruent stimulus locations (see Fig. 3).

Discussion

In order to examine the nature of the Simon effect in the context of automated movement sequences, we explored how execution of two 7 key sequences would be affected by displaying the stimuli on congruent and incongruent positions. We further explored whether incongruent position effects decrease over practice, and whether they would eventually reappear when two unfamiliar sequences are introduced.

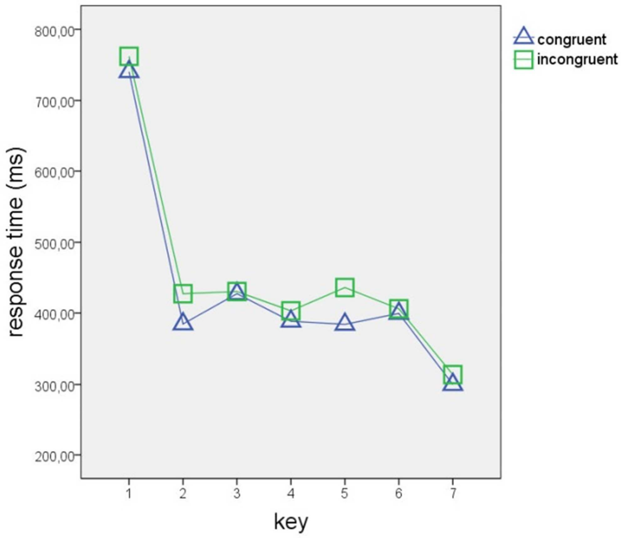

Fig. 3 Response time differences between congruent and incongruent letter positions on keys 1-7 on the familiar sequences during block 7.

Development of motor chunks

The present data supports the hypothesis that performance of the participants on the DSP task increases due to motor chunk development. The support for the hypothesis comes from the findings that both reaction times and error proportions decreased over blocks 2-6. This adjustment is in line with other *discrete sequence production* task experiments (for recent studies, see Abrahamse et al. 2013; Verwey et al. 2015).

Among the plausible explanations for these findings is that motor chunks, response – response associations, could exclude the use of required stimulus-response associations.

Induction and development of the Simon effect

Findings confirm the hypothesis that participants do have significantly longer reaction times and higher error proportions on stimuli with incongruent locations when they begin with learning the keying sequences. This increase of reaction time can be attributed to the Simon effect.

During the test block, we further examined the impact of the Simon effect by comparing the results of automated keying sequences participants were unfamiliar with to the sequences they had previously practiced. In accordance with the third hypothesis, we were able to show that during the test block the Simon effect vanishes over time as reaction times do not differ significantly between congruent and incongruent letter positions. Moreover, results show no impact of presenting the stimuli at one or at one out of four stimulus locations when participants were familiar with the sequence. On the other hand, reaction times increased enormously at the four stimulus location condition within the unfamiliar sequences.

We further examined whether the Simon effect increases again within newly introduced unfamiliar sequences assuming that it would appear within the unfamiliar sequences but not within the familiar sequences. Results rejected the hypothesis as the Simon effect had an impact on reaction times in both, unfamiliar and familiar sequences. However, a closer look revealed the striking observation that the Simon effect only affected reaction times of two out of the seven keys within the familiar sequences.

Execution of the discrete keying sequence

The present pattern of the familiar keying sequence during the test block is generally consistent with findings of past studies by Abrahamse et al. (2013) in which the first key response marks the initiation and therefore is executed fairly slow. The relatively slow response half way through, which indicates concatenation, is typically observed in higher sequence lengths (Verwey et al., 2015). In the present study this peak in reaction time can be observed at the third key when the stimulus is at a congruent location. However, when stimuli are displayed at incongruent positions, the second, third and fifth key response takes approximately the same amount of time, whereas the fourth key response, in the middle, takes a relatively short reaction time.

The fact that stimuli at incongruent letter positions cause higher reaction times is in the lines of earlier literature and was explained by the idea that participants confronted with unpredictable stimulus locations fall back to responding to individual stimuli (Verwey & Abrahamse, 2012). Still, significantly higher reaction times were only observed at two out of the four key presses.

The decrease of reaction time at the sixth key, as well as the fairly short reaction time on the seventh key could be explained by awareness. Recent studies suggest that explicit knowledge is particularly important for the last response in a sequence (Verwey, 2015). Although this statement was based on a six-key sequence, evaluating the present awareness task could confirm this idea.

Concluding remarks on the mechanisms underlying the Simon effect

Although the Simon effect can still be observed in automated movement sequences, the fact that not all keying responses were affected could contribute to the recently ongoing debate on cognitive mechanisms underlying the Simon effect. In this debate, Hommel et al. (2001) introduced the *Theory of Event Coding* that relates the decay of the Simon effect to either the onset of the stimulus, the moment of selecting the stimulus or the moment of retrieving a stimulus from memory. During the test block, the onset of stimuli in unfamiliar sequences did not differ from the onset of stimuli in familiar sequences. Furthermore, participants were not able to retrieve stimuli from memory as the unfamiliar sequences were newly introduced. Although participants selected the unfamiliar sequence stimuli later than the familiar sequences stimuli, reaction times on the unfamiliar sequences were still shorter than reaction times on the practice sequences, when these were newly introduced during the second practice block.

Lubbe and Abrahamse (2011) criticize that Hommel et al. dismissed the *premotor theory of attention*, which suggests that *spatial codes* are attention related. According to this theory, an eye movement program is prepared towards the expected stimulus location, if the stimulus does not appear in the cued location a new eye movement program has to be prepared. Therefore the decay of the Simon effect is predicted to be relative to the moment of *attentional selection* (Lubbe & Abrahamse, 2011). This theory could be better suited to explain the present results as participants seem to have learned over time that stimuli will appear in one of the four placeholders rather than in a specific one. Learning this new eye movement program might be the reason why the Simon effect did not affect all of the keying responses during the test block even though participants were confronted with an unfamiliar sequence containing incongruent stimulus positions.

Further research suggestions

To gain further insights into the underlying cognitive processes of the Simon effect in the context of *automated movement sequences*, a similar research design with added eye movement tracking devices could be applied. For example studies that examine *visual attention* and *target selection* using eye tracking devices see Deubel and Schneider (1996) and Hoffman and Subramaniam (1995). Spotting differences in eye tracking during the DSP task before and after participants habituate to the Simon effect might support the idea of attentional selection as a factor of the decay of the Simon effect.

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