Occurrence of the Simon effect during the DSP task

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Abstract:
During sequence learning memory- and motor chunks can be formed. By performing the Discrete Sequence Production (DSP) task participants either implicitly or explicitly learned sequences. This influenced the Simon effect, an effect where reaction times are longer if there is a difference between stimulus location and response location. The Simon effect became less noticeable during the practice trials. This would mean that participants formed response-response (RR) associations, which they used together with stimulus-response (SR) associations. During the test trials, reaction times between familiar and unfamiliar sequences were not significantly different, this means that the Simon effect still occurred during familiar sequences. Even after having practiced a certain sequence hundreds of times, SR associations are still used.

Keywords: Chunk, DSP, Simon effect, Reaction, Sequence

Introduction

If you are fast using a keyboard, chances are that this is because of sequence learning. An example of sequence learning is typing blindly. Instead of looking at the letter you need to press next, you know what key you should press after the previous one. If you had to look at the keyboard for each letter you had to press, it would take a long time before you have written what you wanted. The most important thing for learning sequences is repetition. When typing a word for the first time, it takes some time. Having typed that word a lot of times ensures that you know how to type it. This knowledge can either be conscious (explicit knowledge) or unconscious (implicit knowledge). If you look at the first letter of a word on the keyboard, and then proceed to type the rest of the word without looking, then you no longer use stimulus response (SR) associations (see the key, press the key) but you use response-response (RR) associations (press the first key, then the second). This paper seeks to find whether SR associations are completely ignored after having practiced a certain sequence many times, or still partially used.

Processing information

Memory chunks were first mentioned by Miller (1956). In his research, Miller explained how people remember information. An important explanation was that people can remember information more easily by dividing it into integrated parts. This is because an individual can only store a limited amount of information in their working memory. For example, instead of remembering the letters AHBGH separately, someone will remember the combinations ‘AH’ and ‘BGH’. This process of grouping information is called (memory) chunking. In the previous example, instead of 5 letters, someone can remember two segments or ‘chunks’. During a reaction task, this would mean that someone who recalls these two chunks will generally be faster than someone who recalls all 5 letters. This ‘recall’ does not have to be explicit, you can

also unconsciously use these chunks. Sternberg, Knoll and Turock (1990) mentioned that responses are generally given earlier within linked pairs than unlinked pairs. If you see chunks as linked pairs, since they form a connection in your head, this means that reaction times are shorter within a chunk compared to reaction times when going from one chunk to the next. This is comparable to something mentioned in Abrahamse, Ruitenberg, de Kleine and Verwey (2013). They mentioned that the first letter in a sequence takes longer to respond to, because people need to prepare for that sequence.

There are several models that explain how information is handled in a motoric task. Verwey (2001) compared single-resource theories (Kahneman, 1973), multi-resource theories (Wickens, 1991) and other processing theories with each other. The dual processor model (Shaffer, 1991; Pew, 1966) was the model that best explained how responses are chosen and executed. This model exists of one motor processor, one cognitive processor, and one motor buffer. The cognitive processor selects individual responses or motor chunks, the motor buffer stores responses and the motor processor executes the responses and movement from the motor buffer.

The Simon effect

The Simon effect had first been described by Simon and Wolf (1963), and was explained in more depth in Simon and Rudell (1967). In this study, participants were given a stimulus they had to act on, in this case the word “left” or “right”. If they were given the command “left” they pressed the left button, and vice versa. Reaction times were found to decrease when the stimulus “left” was given to the left ear and “right” to the right ear. The conclusion was that the location of a stimulus can influence someone’s reaction times. If there is an incongruence between stimulus location and response location, reaction times will be longer. The difference in reaction times between a spatially congruent and spatially incongruent task is known as the Simon effect. (Simon and Berbaum, 1990).

The Simon effect occurs because of a response conflict during the response selection stage (Rubichi, Nicoletti, Iani & Umtilà, 1997). It is uncertain what exactly causes the Simon effect. It might either be because of how a stimulus is perceived (Hommel, 2010,2011) or because of attention shifts (Van der Lubbe and Abrahamse, 2011). Van der Lubbe and Verleger (2002) also mentioned the ‘decay effect’. A process where the Simon effect seems to be less prevalent because participants respond more slowly than earlier in the task.

SR and RR associations

During the DSP task, participants are asked to respond to stimuli on the screen by pressing keys that are spatially congruent with the presented stimulus. When having practiced a certain sequence many times, participants learn the sequence and are able to execute it faster

(Verwey, Abrahamse & de Kleine, 2010; Abrahamse et al., 2013). The first stimulus may be enough for someone to recollect the whole sequence. For example, if participants are given four squares on-screen that offer the letters G, H, J and K from left to right, they might type in the whole sequence 'GHJK' after processing the 'G', without processing the letters H, J and K. According to Verwey (2001) however, the additional stimuli may still be used, even though motor chunks were formed.

The Simon effect occurs when there is a spatial incongruence between stimulus location and response location. When you press the third key, in the previous example the 'K', you would expect it to be in the third square. If the stimulus is shown in another square than the third, the reaction time will be longer. This would not happen if the location of the stimulus is ignored, as could happen in the DSP task. When practicing the DSP task, a response-response (RR) association might be used instead of, or together with a stimulus-response (SR) association. If the RR association would be used instead of the SR association, the Simon effect could not be observed. This is comparable to the expectations of Boutin, Massen and Heuer (2013), who tested explicit knowledge in auditory and visual tasks. They found that once a chunk is made, either by implicit or explicit knowledge, additional stimuli are partially or fully ignored. If this is the case, that would mean that the Simon effect does not occur in familiar sequences.

To answer whether the DSP task influences the Simon effect, you need to know if (a) a memory chunk has formed during the test and if (b) the Simon effect occurs. It is expected that the DSP task repeats a sequence so much that memory chunks form. Memory chunks are the same as RR associations. If only RR associations are used, then it would mean that the Simon effect will not be observed since it occurs because of a difference in stimulus and response location. It is expected that the Simon effect occurs, and that it reduces with practice. Unfamiliar sequences would have an increased Simon effect in comparison to the familiar sequences, because chunking could not occur in unfamiliar sequences. If SR associations are still used then the Simon effect might not be influenced as much. The more RR associations are used instead of SR associations, the more you could see the difference in reaction times after practice and between familiar and unfamiliar sequences.

These questions were examined by letting every participant do six practice blocks, an awareness test and one test block. The practice blocks consisted of 100 trials where they learned two sequences. Once the participants were done with the practice trials, they took an awareness test to see whether or not they explicitly knew the sequence order. The seventh block was the test block, which existed of four subblocks. Two subblocks contained unfamiliar sequences, and two subblocks contained familiar sequences. Both the familiar and unfamiliar sequences had one subblock with one stimulus location (no Simon effect) and one subblock with four stimulus locations (possible Simon effect). By comparing reaction times, the questions whether the Simon effect and chunking occurred can be answered

Methods

Participants

Participants were acquired in one of two ways. Undergraduate students could sign up for the experiment via a university hosted website, and received course credits in exchange. The other participants were acquired using convenience sampling, and received €12,- for their participation. Requirements for the participants were that they did not have any visual impairments or impairment to the hands. There were 16 participants total, 6 male and 10 female, with an average age of 22.3 years and a standard deviation of 3. The study had been approved by the University of Twente ethics committee.

Apparatus

The program used for displaying the sequences, as well as saving the data was E-prime v2.0. The tasks were displayed on a Philips 108t5 lightframe 3 CRT monitor. The computer used was a Dell optiplex 9010 using windows 7. During the test, all additional programs and windows services were turned off so that reaction times could be measured more accurately. The keyboard used was a Dell KB212B keyboard.

Tasks

The tasks consisted of participants pressing the keys C, V, B or N on the keyboard when respectively the letters E, U, R or O were shown on the screen. Participants placed their left index finger on the V and their left middle finger on the C, while their right index finger was placed on the B and their right middle finger on the N. A regular keyboard was used for the responses. As for display, letters were shown in black-lined squares on a white background. Once a letter appeared in one of these squares, the assigned key was pressed. If an incorrect key was pressed, a message would be displayed stating that they had pressed the wrong key. The test was divided into six training blocks consisting of two subblocks each, one awareness test and one testing block consisting of four subblocks. Each block consisted of 50 trials per subblock, for a total of 100 trials, except for the last testing block which existed of 50 trials per subblock for a total of 200 trials. The first six blocks consisted of two sequences, both seven letters long. Block 7 consisted of four subblocks. The first subblock presented an unfamiliar sequence with four letter locations, the second subblock presented the same unfamiliar sequence but only presented the letters in one location. The third subblock presented the familiar sequence with four letter locations while the fourth subblock presented the familiar sequence in one location. Since the Simon effect can only occur if there is a difference in stimulus location and response location it could not occur during the blocks with only one stimulus location.

Sequences were divided in such a way that each letter would be used for every different finger. For example, if one participant was practicing the sequences ‘VNBNVBC’ and ‘NVCVNCB’, the next participant would learn two sequences where every letter is replaced by

one letter to the right on the keyboard, except for the N, which would be replaced by the C. This would mean the next participant had to learn the sequences 'BCNCBNV' and 'CBVBCVN' respectively. Dividing the data like this ensures that changes in reaction times cannot be related to the use of specific fingers. Participants were clearly instructed to always react to the letter shown on screen, not the location of the letter. After each block, mean reaction times in milliseconds and percentage of mistakes were displayed.

Procedure

Participants were first given an information form which they could read at their own leisure. If needed, they would also receive additional information from the experimenter. They were further able to read the information on screen before each block. Once they had understood the task, they signed the informed consent form after which they could start the experiment. Participants were not specifically instructed about the sequences. The participants first had to do 6 blocks, consisting of 2 subblocks with 50 trials each. The first block only showed letters in one location, while block 2-6 showed the letters in four different locations. Each block was divided in such a way that 25% of the stimuli had the same stimulus and response location and 75% had a stimulus location that was different from the response location. Each participant executed a total of 600 trials before they were asked to fill in the awareness test. A 20 second break was offered within blocks, while a two-minute break was offered between blocks. Generally it took between 75 and 90 minutes for participants to finish with the first 6 blocks.

After these blocks participants were asked to fill in an awareness test, the researcher was also present in the room during this test. During this test, participants were instructed to press buttons in the order the sequences had been presented to them. For both sequences, participants were asked to demonstrate in what order the stimuli appeared in the squares. They were also asked to demonstrate the order of the sequences with the letters C, V, B and N. They also were asked about the order of the sequences with the letters E, U, R and O. During this test, the keyboard was removed from sight. Once they answered what they thought was the order of the keys, a few additional questions were asked. Participants were asked how they remembered the order and how sure they were this was the correct order. They did this for the squares, the letters CVBN and the letters EURO separately. Answer alternatives for the first questions were (in Dutch): (A) "I remembered the order of the letters on the keys", (B) "I tapped the sequence on the table using my fingers", (C) "I tapped the sequence in my mind" (D) "I remembered the position of the squares and keys" or (E) "I could not remember and had just guessed". The answer alternatives for how sure they were this was the correct sequence were (in Dutch): (A) Very unsure, (B) A bit unsure, (C) A bit sure or (D) Very sure. Finally, they were asked whether or not they participated in any comparable experiments in the last few months or years. Once this awareness test was completed, block 7 was started. In this block, both the familiar sequences and two unfamiliar sequences would be offered. Once this was done, participants were thanked for their help. The whole experiment generally took between 120 and 135 minutes.

Data analysis

For both the practice and the test blocks, reaction times and errors were collected. There were no outliers that had to be removed before data analysis. Data from the awareness test are not reported here.

Reaction times were determined by the time between showing the stimulus on screen and the participant pressing a button. If an incorrect button was pressed, it was counted as an error. The error proportions were arcsin transformed because of deviations from ANOVA assumptions. (p. 356 in Winer, Brown & Michels, 1991).

Results

Practice trials

The reaction times in the practice trials were analysed using a 5 (block 2-6) x 2 (congruent or incongruent) x 7 (keypresses) repeated measures ANOVA. The reason block 1 was left out was because block 1 only contained one letter location, instead of four like in the other blocks.

The main effects of Block, $F(4,60)=48.11$, $p<.001$, Congruency, $F(1,15)=97.96$, $p<.001$, and Key, $F(6,90)=20.65$, $p<.001$ were all statistically significant. Each new block, the average reaction time decreased. Participants responded slower on incongruent trials in comparison to congruent trials and the first key took longer to press than any of the other keys.

The interaction effects of Block x Key, $F(24,36)=4.172$, $p<.001$, Congruence x Key, $F(6,90)=8.11$, $p<.001$, and Block x Congruence, $F(4,60)=6.74$, $p<.001$ were also all statistically significant. Each individual key was pressed significantly quicker than that key being pressed during the previous block(s) and participants were slower when the location of the letter in the square was different from the location of the key they had to press. Each new block also influenced the difference between reaction times of congruent and incongruent trials.

As can be seen in Figure 1, both in congruent and incongruent trials the reaction time per block decreases significantly. What can also be seen is that the difference in reaction times between congruent and incongruent trials become less. This is especially noticeable when comparing block 2 and 3 with each other.

To analyse the arcsin transformed error data a 6 (block) x 2 (congruence) x7 (key) repeated measures ANOVA was carried out. The average number of errors made in block 1-6 was 2.59%, with a standard deviation of 1.03%. The main effects of Congruency, $F(1,15)=70.4$, $p<.001$, and Key, $F(6,90)=2.67$, $p=.036$, were significant, while Block did not have any significant effect on the number of errors, $F(5,75)=3.31$, $p=.053$.

The Block x Congruence interaction was significant, $F(5,75)=7.95$, $p<.001$. The interaction of Block x Key did not show any significant effect, $F(30,450)=0.93$, $p=.572$. Congruence x Key also did not show any significant results, $F(6,90)=1.51$, $p=.184$. Both Block x

Key and Congruence x Key showed significant results when looking at reaction times, but they did not influence the number of errors made.

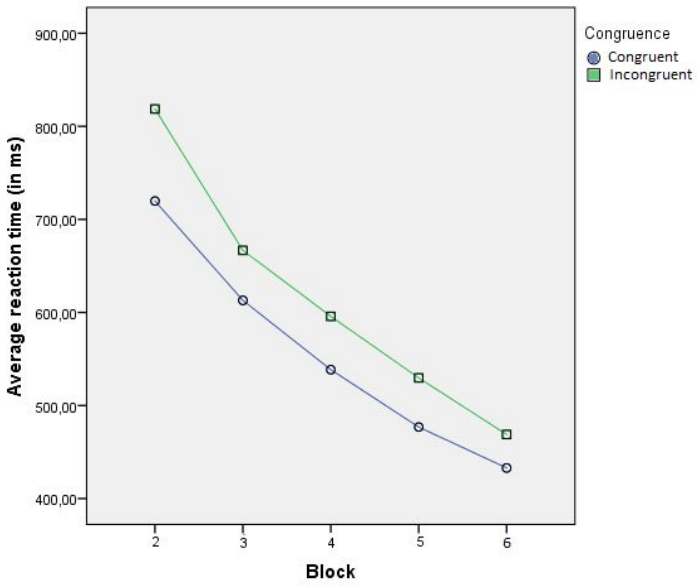

Figure 1, Difference between congruent and incongruent trials per block

Test trials

The reaction times in block 7 were analysed using a 2 (Familiarity) x 2 (4 or 1 Location) x 2 (Congruence) x 7 (Key) repeated measures ANOVA. The main effects of Familiarity, $F(1,15)=39.64$, $p<.001$, Location, $F(1,15)=11.81$, $p=.004$, Congruence, $F(1,15)=12.06$, $p=.003$ and Key, $F(6,90)=31.65$, $p<.001$, were all statistically significant. This means that in the test trials there was a significant difference in reaction times between unfamiliar and familiar sequences, a significant difference in reaction times between one or four stimulus locations and a significant difference in reaction times between congruent and incongruent trials as well as a difference per key. Since there is a difference between congruent and incongruent trials, the Simon effect occurred in both the practice trials and test trials.

Even though there is a significant difference between unfamiliar and familiar sequences, the interaction effects Familiarity x Key, $F(6,90)=0.90$, $p=.501$, and Familiarity x Congruence, $F(1,15)=0.40$, $p=.535$, were not statistically significant. This means that the difference in reaction times of congruent and incongruent trials or the difference in reaction times per key are about as big in the unfamiliar trials as in the familiar trials. Congruence x Key was also not significant, $F(6,90)=0.99$, $p=.439$, even though this effect was significant during the practice trials. This means that the Simon effect can not be observed per key, while it does take place. The interaction effects that were significant were Familiarity x Location, $F(1,15)=5.13$, $p=.039$, Location x Congruence, $F(1,15)=39.56$, $p<.001$ and Location x Key, $F(6,90)=2.27$, $p=.043$. Here you can see that location has a big influence on reaction times.

In Figure 2, congruency with only one location does not mean much. A trial can not be incongruent with only one stimulus location. In this figure you can clearly see, however, that with four locations there is still a big difference in congruent and incongruent trials.

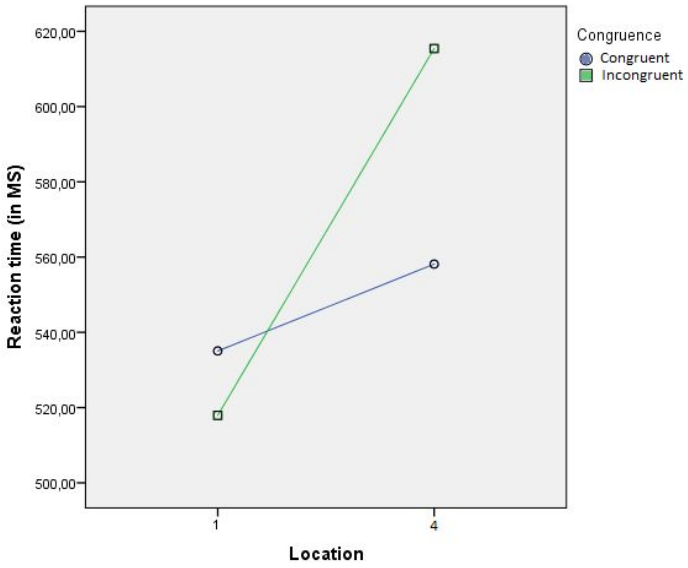

Figure 2, The effect of number of locations on congruence

In Figure 3 you can clearly see that in both the unfamiliar and familiar sequences incongruent trials have a longer reaction time than congruent trials. Average reaction times in the unfamiliar sequences are significantly higher than in the familiar sequences. When the congruent and incongruent points overlap, the stimulus was not used. For key 2, 5 and 7 this happens more clearly in comparison to the other keys.

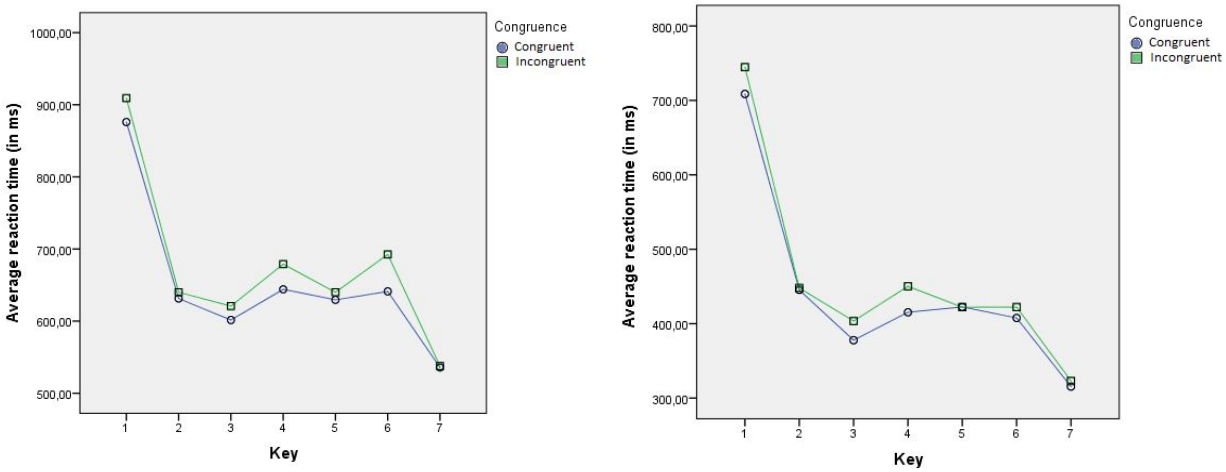

Figure 3, Congruence x Key in unfamiliar (left) and familiar (right) sequences.

The same ANOVA that was used to analyse the reaction times in block 7 was used to see if familiar or unfamiliar sequences influenced the number of errors made. The average number of mistakes made in block 7 was 3.25% with a standard deviation of 2.00%. Familiarity, $F(1,15)=18.9$, $p<.001$, Location, $F(1,15)=12.47$, $p=.007$, and Key, $F(6,90)=7.00$, $p<.001$, were all statistically significant while Congruence was not, $F(1,15)=1.36$, $p=.261$. Congruency did not influence the number of errors made, while it did influence the reaction times. Familiarity, Location and Key had both an effect on the reaction times as well as the number of errors.

The interaction Familiarity x Congruence was significant, $F(1,15)=10.29$, $p=0.006$. The other interaction effects were not statistically significant. The only interaction that was not significant that is worth mentioning is Familiarity x Key, $F(6,90)=1.44$, $p=.2084$. As with the reaction times, there does not seem to be a difference in number of errors per key for unfamiliar or familiar sequences.

Discussion

To answer the question whether or not RR associations were used instead of SR associations, the Simon effect was studied in a DSP task. To see whether or not the DSP task influences the Simon effect, we have to know if (a) chunking occurred and (b) if the Simon effect occurred. Chunking did indeed occur, this can be clearly seen when looking at Figure 1. Reaction times during the practice trials are significantly lower each block. This is according to expectations, a sequence is repeated so much that eventually the sequence is known, which results in shorter reaction times. Some participants also specifically mentioned that they found out there was a sequence and typed it out without really thinking about it.

In Figure 1 you can also see that the Simon effect occurred. There is a clear difference in reaction times between congruent and incongruent trials. The Simon effect reduces with practice, since the difference in reaction times between congruent and incongruent trials becomes smaller each block. The Simon effect did not fully disappear though, at the end of block 6 there was still a difference in reaction times between congruent and incongruent trials.

During the test trials, reaction times in unfamiliar sequences are significantly higher than in the familiar sequences. This clearly shows that chunking did influence the reaction times for the familiar sequences. The Simon effect still takes place during both the unfamiliar and familiar sequences, which can be clearly seen in Figure 2 and Figure 3. In Figure 2 you can see that there is still a big difference between congruent and incongruent trials when stimuli are presented in four different locations, so the Simon effect still occurs. In Figure 3 you can see the differences in the unfamiliar and familiar sequences. If the points overlap, the stimulus is not used. You can clearly see that the stimulus is not used with key 2, 5 and 7, but the stimuli are used for the other keys.

Both chunking and the Simon effect occurred and the Simon effect reduced with practice

in block 2-6. During the practice trials, RR associations were used as well as SR associations. If SR associations were not used at all, the Simon effect would have completely disappeared. In block 7, there was a difference in reaction times between unfamiliar and familiar sequences, which is because of chunking. The Simon effect still occurred in both familiar and unfamiliar sequences. During the practice trials, RR associations developed, but in the test trials SR associations were used anyway. For both the practice blocks and the test block, congruency did not seem to affect the number of errors that participants made. The most important notion that can be made about the errors is that not many were made during the experiment, so this did not influence the results in a major way.

Even though participants could become tired after a while, which some participants reported they were, it was decided to do 100 trials per block. This is because participants still improve in learning a sequence after many trials. This was comparable to an experiment by Crossman (1959), where he found that people still learn something from certain actions, even after having done them ten thousands of times. The reason this tiredness might have been important is because of the 'decay effect' (Lubbe and Verleger, 2002); the Simon effect may seem to disappear if responses are given more slowly. It is likely that responses are given more slowly when participants are tired. Since the Simon effect was still observed, the decay effect did not occur.

Some participants also mentioned that playing video games made it really easy for them to respond on certain sequences. According to Verwey (2015), certain skills like playing the piano could indeed cause decreased reaction times during comparable trials. If there really would be a significant difference in reaction times between people who play the piano, play video games or other comparable things, it might influence certain studies. Possible differences did not influence this study, because only the difference in reaction times per participants was important here, not the overall speed of participants' reactions.

A comparable experiment had been concurrently done by Ruben Grasemann (unpublished bachelor project, 2016). The experiment was the same, except for the fact that in his study the ratio of congruent and incongruent trials was 50/50 instead of 25% congruent and 75% incongruent. His study generated roughly the same results as this study, so the ratio of congruent or incongruent trials does not influence the results. His study showed a significant effect of Familiarity x Key, while the current study did not show these results.

Something that both his and the current study showed was the fact that stimuli tended to not get used at the end of a sequence. This is something we did not look for in this study. When looking at Figure 3, you can see that certain points overlap, this means that the reaction times in congruent and incongruent trials were the same, so the stimulus was not used. If the stimulus is not used, the Simon effect does not occur. Both explicit knowledge and chunking can affect the stimuli not being used (Verwey, 2015). It would be interesting to study what exactly causes certain stimuli to not be used, and then to re-do the current study. If stimuli are not used anymore at all, the Simon effect will not occur.

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