Are automated behaviors still influenced by stimuli in a practiced discrete sequence production task?

Bachelor Thesis by

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Abstract

In this experiment it was investigated whether stimuli still have an influence on an automated sequence behavior. The theoretical underpinning was the *dual processor model* (DPM), which indicates that two different processors try to trigger a response. The cognitive processor reacts to visual indications and triggers each response one by one. The motor processor works with motor chunks, and is able to concatenate them. The hypothesis of the present study was, that stimuli have an influence on automated behavior in a direct sequence production task. The results found in this experiment confirm the hypothesis. Automated sequence behavior is still influenced by stimuli, due to the fact that the cognitive processor is also active and sometimes triggers a response, instead of the motor processor.

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1. Introduction

Driving a car for the first time is difficult and it seems nearly impossible to keep attention to all the tasks. But several weeks later it is getting easier, and a year later it becomes natural to ride a car. People learn the necessary motor skills and are able to execute them without using much of their cognitive attention, it becomes partly unconscious. For example, shifting gears while keeping attention on the street, and this is only one instance of many. Due to consistent practice it is possible to build so-called motor chunks (Verwey, 1994). These motor chunks represent a specific movement sequence, which can be selected as a whole and executed. All the small single movements in a sequence, which would demand cognitive attention if they are executed for the first several times, can be chained together and executed as one sequence(Acuna, Wymbs, Reynolds, Picard, Turner, Strick, Grafton, & Kording 2014). Motor chunks are stored in long-term memory and can be retrieved from it, and loaded into a short-term motor buffer.

Loading the motor chunk into the motor buffer is a preparation for the movement sequence, before it is actually executed (Abrahamse, Ruitenberg, De Kleine, Verwey, 2013). It is possible to investigate the cognitive usage behind it with two different experimental paradigms, motor adaption and motor sequence learning (Doyon, Penhune, Ungerleider, 2003). The focus of the present study lies on motor sequence learning. Tasks that focus on motor sequence learning refer to learning specific movements (sequences) until they reached a level of skilled behavior. Different indicators exist to determine improvement. For example, reaction time, or error proportion during the performed behavior/task. Such a task is the *discrete sequence production* task (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004).In a DSP task participants react to two alternative sequences with a length of two to seven stimuli. The reaction involves a specific key press, which is directly followed by the next one in the sequence. Due to the relatively small number of elements in a sequence, it is possible for the participants to recognize each sequence easily and learn them. Earlier findings show that participants often reacted slower to the first stimulus of a sequence as well as to the one halfway through (Abrahamse et al. 2013). The remaining responses (in a seven element sequence), however, are executed very fast after sufficient practice. A theory for the slower reaction to the stimulus halfway through is given by the study of Verwey (2001), with the assumption that a motor chunk can hold up to four or five elements. That means a sequence with seven elements is split into a motor chunk with two subsequences (Wymbs, Bassett, Mucha, Porter, & Grafton, 2012; Verwey, Abrahamse, & Jiménez, 2009). The transition from one subsequence to the next is slower, which is indicated by a slower reaction time and is therefore called concatenation. The DSP task is used to investigate preparatory mechanisms, hierarchical control, sequence segmentation and serial position. Such a DSP task will also be used in this study. The *dual processor model* (DPM) will be used as a theoretical underpinning, to explain the phenomena obtained with the DSP task (Verwey, 2001)

The DPM assumes that two independent processors are acting simultaneously while executing discrete movement sequences (Abrahamse et al., 2013). These two processors are a cognitive and a motor processor. Initially, the cognitive processor selects each movement and loads its representation into the motor buffer, which triggers the motor processor. The motor processor uses the information from the motor buffer and executes the actual movement. If a situation or the sequence is unknown, it takes more time to react to the stimuli, since the cognitive processor needs to select every single reaction and loads every response into the motor buffer. This is also called the *reaction mode* (Verwey, Shea, & Wright, 2014). After practicing a sequence and building a motor chunk, it is possible for the cognitive processor to retrieve the motor chunk from long-term memory and load this motor chunk into the motor buffer. This way of execution is faster than loading every single response into the motor buffer and it also means reduced processing load for the cognitive processor. The motor processor is autonomous during the execution of motor chunks, it just needs the motor chunk from the cognitive processor. This is called the *chunking mode.*

Both of these processors, the cognitive and motor processor, are working in parallel (Verwey, 2001) in tasks like the DSP task. This is also the reason why it is called concurrent, or on-line programming. Both of the processors trigger a reaction and one wins the race. Overall the chunking mode is faster, because the representation is already in long-term memory. But there is always a possibility that the reaction mode is somewhat quicker. That means even though one of these two might be slower on average, the execution rate will increase by concurrent activity. It is also possible to stop the concurrent operation by assigning a different task to the cognitive processor, like counting tones in the background while reacting to the sequences (Verwey, Abrahamse, De Kleine, & Ruitenberg 2013).

Studies exist about *reaction-stimulus interval* (RSI) effects in reaction time based experiments. For instance the studies of Rabbitt (1969) and Willingham, Greenberg & Thomas (1997). But there is none about RSI effects within DSP tasks.Therefore the goal of this study is to look for RSI effects within a DSP task and if it delivers conclusions about the state of the stimulus-response channel (shown in Figure 1). This hypothetical channel has two different states, open and closed. When the channel is open a stimulus is needed to trigger a response, which is comparable to the reaction mode. When the channel is closed, a stimulus cannot to trigger a response. This should be the case during the chunking mode. Except for the first stimulus of a sequence, none are needed to react to the following ones, because they are already learned and represented in the motor chunk.

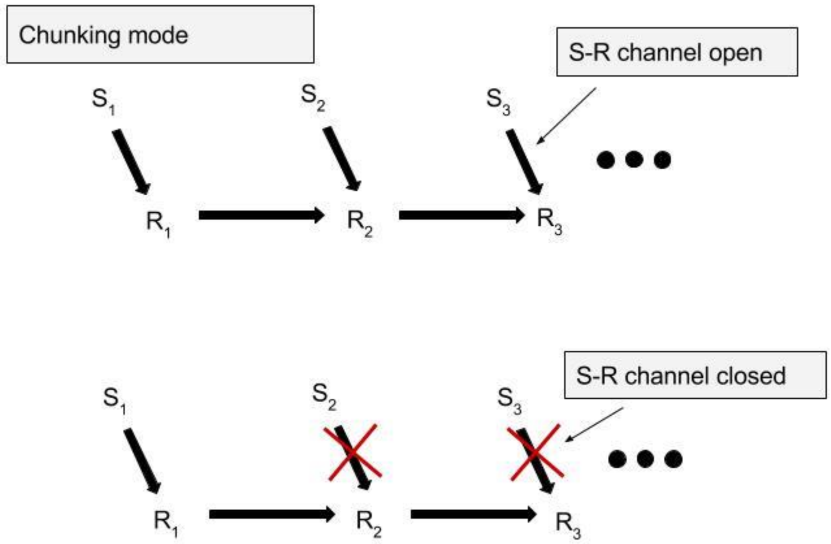

Figure 1; Chunking mode of the dual processor model, represented with both states of the hypothetical S-R channel.

In this DSP task, the participants had to responde to two different sequences with a length of seven elements each. The overall experiment consisted of six blocks. The first five constituted the practice phase and the last one involved the test phase. In the practice phase the participants responded to stimuli on a computer screen, by pressing the proper key. After reacting successfully to a stimulus the next stimulus of the sequence showed up immediately with a RSI = 0 ms. The test phase was divided into three different parts. The first part was exactly the same as the task within the practice phase (100/0, 0 ms condition). The second part consisted of a modified task in which stimuli after the first of each sequence was delayed with RSI = 800 ms (0/800, 800 ms condition). The third part was a mix of the first and second part (20/0, 80/800, mixed condition). 80% of the stimuli were delayed during this phase RSI = 800 ms, and 20% appeared with no delay, RSI = 0 ms (shown in Figure 2). If the participants gave a response before a stimulus was displayed, the stimulus was not displayed, instead was followed automatically by the next one.

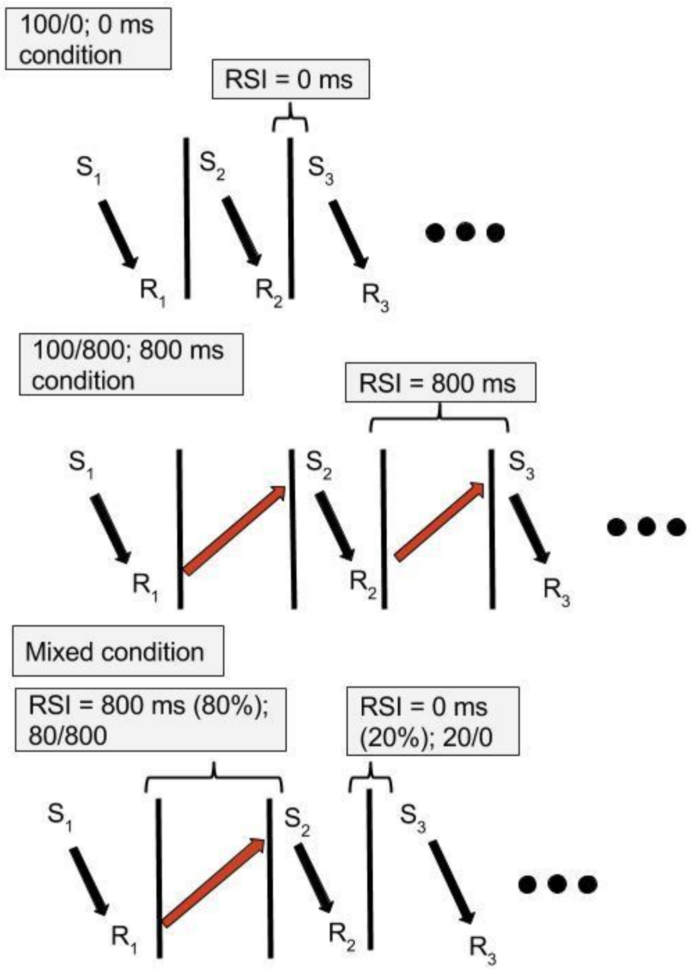

Figure 2; Representation of the test phase, each subblock and the containing conditions.

The main interest of this experiment lies in the third part of the test phase. Especially in the reaction time on the directly displayed stimuli. The participants expected less that the stimuli would be displayed due to the distribution of delayed and directly displayed stimuli. It is expected that the participants used the chunking mode to react to the stimuli. If a stimuli is then directly displayed it might be the case that the participants react faster to such. An explanation would be the usage of the stimulus, which indicates that the stimulus-response channel is still open and influences the response. Therefore the purpose of the present study is to examine the effect of low-probability stimuli during an automated sequence and if they speed up the responses.

2. Methods

2.1 Participants

All participants were students at the University of Twente in Enschede. 24 Participants took part in the experiment (15 female and 9 male) and varied in age from 18 to 44 years ($M = 20$ years, $SD = 4.92$). The participants had normal vision or a vision correction as well as no color blindness. They were all able to perceive the stimuli in an adequate manner. Every participant signed an informed consent at the beginning of the experiment. The experiment itself was approved by an ethical committee.

2.2 Materials

The experiment took place under laboratory conditions. The test itself was created with a psychology software tool, called E-Prime 2.0. It ran on an Optiplex X 9010 from Dell with Windows 7. The CRT monitor used was a Philips 107 T5, and the keyboard was a Dell Keyboard KB212-B.

2.3 Task

Participants reacted to the filling of one of four placeholders, displayed on the screen. One placeholder changed the color to green-blue and the participants responded with the appropriate key press. The changing of the color occurred in one of two possible sequences, that were repeated over the whole course of the experiment. The response keys were C, V, B and N on the keyboard. It was required to use the left hand. The pinky on C, the ring finger on V, the middle finger on B and the index finger on N. The stimuli on the screen were given to the reactions in a spatial compatible way. The box on the left corresponded to the C-key, the box in the middle left towards the V-key, and so on. Four different sequences with a length of seven stimuli were used in this experiment, they were used in two pairs. The first pair was *VNBNVCB* and *NVCVNCB.* The second pair was *BCNCBNV* and *CBVBCVN*. 12 participants performed the test with the first pair of sequences and the other 12 with the second pair. One of the sequences within each run also had a break after the fourth stimulus, with the idea of creating controlled subsequences. The break was in a different sequence for each participant, so that it was balanced between every sequence.

The test overall consisted of six blocks. The first five blocks represented the practice phase. Each block consisted of 240 sequences, 120 for each of them. The participants had a break of 40 seconds halfway through and 4 minute breaks after each finished block. The sixth block represented the test phase. This block was divided into three subblocks. One subblock had a similar task like in the practice phase, with the exception that there was no break in one of the sequences. Another subblock had a RSI of 800 ms. In this block it was possible to react towards the stimulus before it was displayed. If the participants were able to automatize the sequence, it was no problem to react in a similar pace like before. The third subblock was a mix of the other two subblocks. The RSI in this block had a chance of 80% to result in 800ms and therefore a chance of 20% to result in 0ms.

The overall experiment took about 2.5 hours. The program started with a short instruction of the task during the experiment. The screen during the actual task was grey with four placeholders in form of squares in the middle of the screen (shown in Figure 3). The stimuli were represented by a color change of a placeholder to a green-blue color. The colors were chosen to overcome any luminance effect, so that participants reacted to the color change and not to any intensity changes. During the breaks a countdown appeared on the screen indicating the time people had before the next half or block starts. There also was an indication of the average reaction time and the amount of mistakes that were made in percentage on the screen. It was important for the participant not to cross the 8% mark. If a participant made more mistakes than 8%, it was necessary to retake the block.

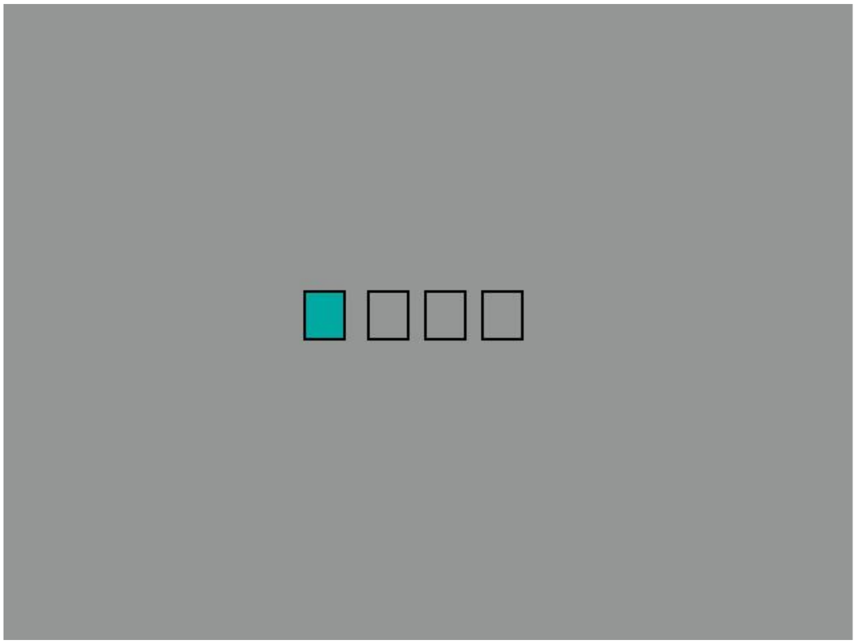

Figure 3; Placeholders in the DSP task.

2.4 Design and Procedure

The research design of the present study was experimental within sutbject as it studied the reaction time and error proportion of participants on unexpected stimuli. The independent variables in this experiment were, the delay of the stimuli, whether the sequence was learned with a pause or not and the keys that were used.

At first the participants were asked to sign an informed consent (see appendix A). After that a short instruction was handed out (see appendix B), the participants received further explanation by the researcher. They got the information that they would take part in a reaction time test and that they had to make as few mistakes as possible, while also giving explanations about the actual task they were going to do. After the instructions a color blindness test (see appendix C) was done with each participant, to ensure that they would have no problems recognizing the stimuli. Next, the participant read the instructions of the experiment that were displayed on the screen, while the researcher waited for any upcoming questions. After that, the researcher stayed for a short amount of time during the running task to make sure that the participant understood the task and had no problems recognizing the stimuli. The researcher went into the room after each four minute break to set up the next block. Before running the test-phase, the participants obtained further instructions about the upcoming task from the researcher as well as the introduction displayed on the screen. After each subtask of the test-phase, the participants were asked if he or she understood the task correctly. After finishing the test-phase the participants were asked whether it had been possible to react to the delayed stimuli. With this question the experiment ended and the participants got the chance to ask any questions related to the experiment.

3. Results

3.1 Practice phase

To analyse the reaction time (RT) and error proportion (EP) data, gathered with the practice phase, repeated measurement ANOVAs were used. The ANOVAs were conducted with a 5 (Block) x 2 (Pause) x 7 (Key) design for five practice blocks, pause or no pause, and seven different keys. These were used as independent variables, while the RT or EP were the dependent variables within these analyses. The raw EP data was transformed with an arcsine transformation in order to make it applicable for parametric tests.

A significant effect was found for Block on RT, $F(4, 92) = 299.6$, $p < 0.001$, the mean RT descended with the ongoing blocks, from 441 ms mean RT in the first block to 214 ms mean RT in the fifth block. Pause had no significant effect on RT, $F(1, 23) = 2.2$, $p < 0.152$. A significant effect was found for Key, $F(6, 138) = 97.3$, $p < 0.001$, on the first key, participants reacted with a mean RT of 453 ms. The next slower reaction was in the fifth key with 324 ms. On the other keys, the participants reacted between 244 ms to 284 ms. An interaction effect was found between Block on Key, $F(24, 552) = 27.6$, $p < 0.001$, the mean RT on the fifth key did not improve over the course of the blocks in comparison to the other ones, except key one (shown in Figure 4). There was an interaction effect between Pause on Key, $F(6, 138) = 5.8$, $p < 0.001$. Participants reacted faster on the fifth key if no pause was included in the sequence, the mean RT on the fifth key in the no pause condition was 296 ms versus 352 in the pause condition. The RT on the fourth and sixth key were faster in the pause condition with 242 ms, 228 ms versus 269 ms, 280 ms in the no pause condition. Overall, RTs in the pause condition were faster than RTs in the no pause condition, excluding the RT on the fifth key.

Block had a significant effect on EP, $F(4, 92) = 6.3$, $p < 0.001$, the EP increased over the course of Block, beginning with a mean EP of 1.3% in the first block increased up to 2% in the fifth block. Pause had no significant effect on EP, $F(1, 23) = 0.4$, $p < 0.556$. Key had a significant effect on EP, $F(6, 138) = 11.1$, $p < 0.001$, the smallest EP on the first key amounted to 0.9% versus 2.3% on the second key, which was also the highest amount of all keys. The analysis showed a significant interaction between Block on Pause, $F(4, 92) = 2.6$, $p < 0.043$. The EP in the first two blocks was higher in the pause condition with 1.4%, 1.7% versus 1.3%, 1.4% in the no pause condition. In block four and five it was vice versa, 2%, 2.3% in the pause condition versus 1.8%, 1.7% in the no pause condition. Another significant interaction existed between Block on Key, $F(24, 552) = 3$, $p < 0.001$. The EP of key two and six increased the most from block one to five. Both contain the highest EP in the fifth block with 2.7% and 3.1%. The other keys did not increase as much, excluding key one and seven, they both decreased in comparison of the first and fifth block. Key one decreased from 1.2% to 0.9% and key seven decreased from 2.4% to 1.3%

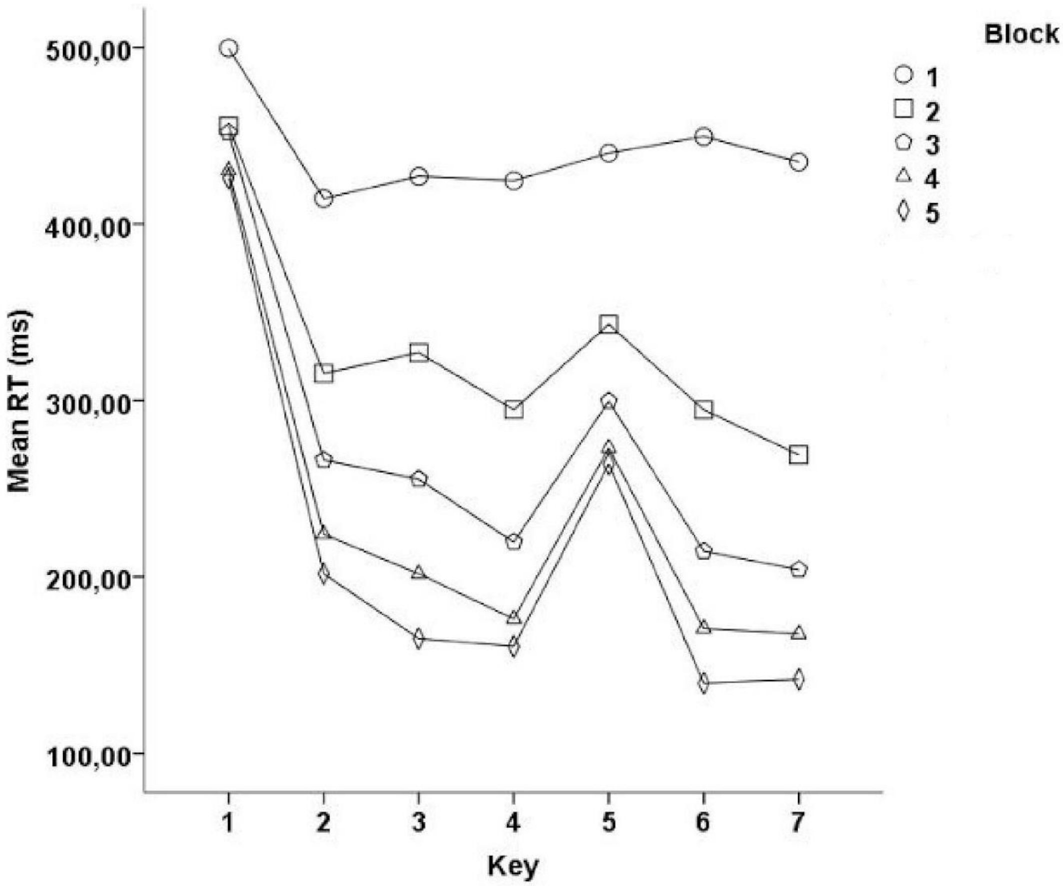

Figure 4; Mean RT comparison of each block in the practice phase, showing the effect of the Pause on R_5.

3.2 Test phase

Two repeated measurements ANOVAs were used for the RT and EP data of the test phase. A 4 (Delay) x 2 (Pause) x 6 (Key) design was used for the RT data and a 4 (Delay) x 2 (Pause) x 7 (Key) design for the EP data. The independent variables were Delay (consisting of the four conditions in the test phase, 100/0, 20/0, 80/800 and 100/800), Pause (w/o pause at S_5, during the practice phase), Key (RT: 6, EP: 7). For the RT a 4x2x6 design was chosen, because S_1 was never delayed. The raw EP data was transformed with an arcsine transformation.

The RT analysis showed that Delay had a significant effect, $F(3, 69) = 10$, $p < 0.001$ (shown in Figure 5). Pause had no significant effect on RT, $F(1, 23) = 0.4$, $p < 0.526$. Key had a significant effect on RT, $F(5, 115) = 28.6$, $p < 0.001$. The mean RT on the second and fifth key were higher in comparison to the others, with 237 ms and 262 ms. The mean RT for key three, four, six and seven were below 200 ms.

A significant interaction effect was found for Pause on Key, $F(5, 115) = 8.2$, $p < 0.001$, (shown in Figure 6). The RT of the fifth key differs between the pause and no pause condition. When the sequence was learned with a pause during the practice phase it had a mean RT of 308 ms in comparison to no pause of 216 ms. Another ANOVA with a 2 (Delay) x 2 (Pause) x 6 (Key) was conducted. The independent variables in Delay were the 20/0 and 80/800 condition, Pause and Key were the same as in the other ANOVAs. The RT analysis confirmed the significant effect of Delay, $F(1, 23) = 11.2$, $p < 0.003$. The 20/0 condition had a mean RT of 189 ms versus the 80/800 condition of 202 ms.

The conducted EP analysis showed that Delay had a significant effect, $F(3, 69) = 3$, $p < 0.035$. The EP differed in each condition of the Test phase, between an EP of 2.5% for 100/0 and 20/0, EP of 2.4% for 80/800 and an EP of 2.3% for 100/800. Pause had no significant effect on the EP, $F(1, 23) = 0.9$, $p < 0.366$. Key had showed a significant effect on EP, $F(6, 138) = 3.8$, $p < 0.002$. The EP differs from 0.9% on the first Key, to 3.5% on the sixth key.

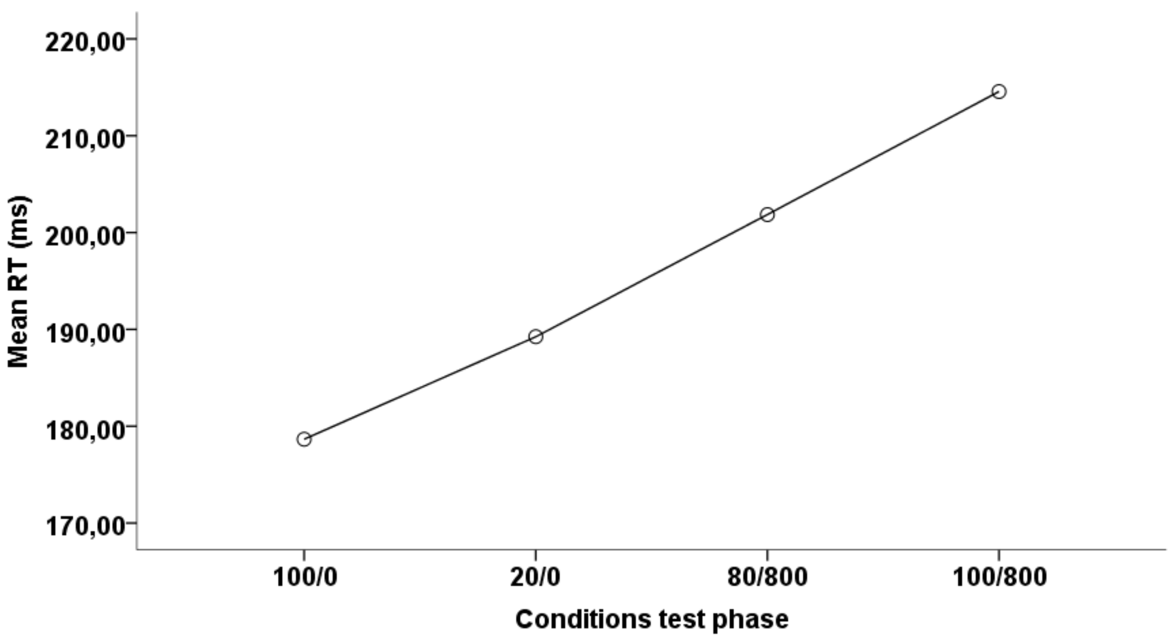

Figure 5; Comparison of mean RT of the four conditions in the test phase, showing that 20/0 is faster than 80/800.

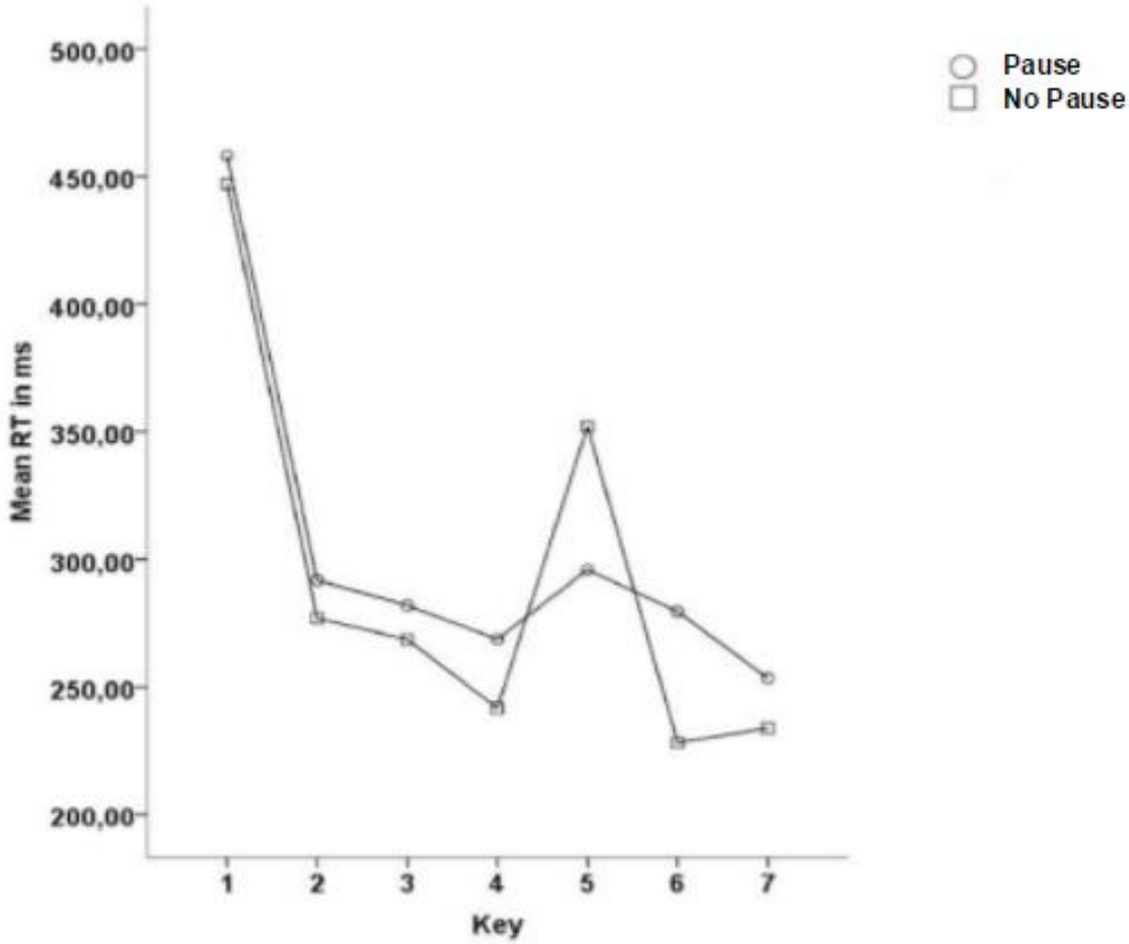

Figure 6; Comparison of the sequences with pause between S_4 and S_5 during the learning process and no pause.

4. Discussion

4.1 Hypothesis

The purpose of this study was to investigate if automated behavior in the form of sequences are still influenced by stimuli, thus the hypothetical S-R channel has to be open. This hypothesis was based on the dual processor model, which indicates two processors that are involved in automated processes. The cognitive and the motor processor try to trigger a response, but only the faster one will actually be executed. The cognitive processor uses the reaction mode, reacting to every single stimulus, while the motor processor uses motor chunks, stored in long term memory. Specifically, these two modes were investigated with the discrete sequence production task. When the reaction mode is still used during an automated process, it would strengthen the DPM as well as giving more clues about automated behavior. Thus the experiment tried to generate such a case, through presenting unexpected stimuli.

The results showed that in the test phase, RTs in the 20/0 condition were significantly faster than RTs in the 80/800 condition (shown in *Figure 5*). This outcome supports the hypothesis, that a stimulus is still used during automated sequencing behavior. It also indicates that two different processors might be at work during the whole process, which supports the DPM. Thus based on the results, it is possible to say that stimuli are still used during automated behaviors in a DSP task and the stimulus-response channel stays open.

4.2 Further outcomes

Over the course of the practice phase it was possible to see how the participants were able to react faster to the sequences. This was confirmed by the statistical analysis of Block from the practice phase (shown in *Figure 4*). Interesting is that people reacted slower to S_5 in comparison to the others, due to the implemented pause. The participants were still able to get faster over time but the gap between R_5 and the other reactions got bigger with each consecutive block. Moreover, this effect was stronger if the pause was inserted by the researcher, by a changed RSI. Especially during the test phase it was possible to see, that the RT on R_5 was longer if participants had learned the sequence with a pause after R_4 (shown in *Figure 6*).

4.3 Conclusions

The study showed that stimuli are still used during automated behavior. In order to strengthen this outcome, a follow up study with slight changes would be recommended, which would show the reproducibility of the present study. Another aspect would be the robustness and how the effect changes over time, in the sense of extending the practice phase over multiple sessions. This would create a better view of this effect on even stronger automatized behavior.

Another point is the effect in comparable situations. Thus it would be possible to show that there is no more race between the two processors, if one of them is engaged in another task. Comparable to the experiment of Verwey (2013), it could be revealing to do a DSP task, while counting random tones in the background. The cognitive processor should be focused on the tone counting task, while the motor processor would be engaged in the DSP task. The stimuli should not affect the automatized behavior anymore in that case. It could also be interesting how stress is influencing the usage of the two processors. Hence an experiment with different stress levels could be interesting to conduct. It is commonly known that people react different in stressful situations and that could change the expected outcomes. Taking the example of the introduction, riding a car, which for most people is an automatized behavior. But there are situations while riding a car that can be really stressful, for instance an accident. It might be helpful to see how automated behavior changes under pressure, in order to understand why certain situations brought up unexpected outcomes.

Interesting outcomes were also found on pauses within automated behavior. It might be interesting to investigate if the effect of a pause disappears with more practice, or if it just approaches the RT of the other reactions within a sequence. It also seemed that people were faster in learning the sequences, when a pause was included. The RT did not differed significantly, but the EP was significant lower in the sequence with a pause than vice versa. As a result of this, it could be possible that slightly more complex sequences could be learned faster and better, through including a pause during the practice.

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Appendices

Appendix A: Informed consent

Informed consent form

Title research: RSI Effects in a DSP task
Responsible researcher: prof. Willem Verwey

To be completed by the participant

I declare in a manner obvious to me, to be informed about the nature, method, target and [if present] the risks and load of the investigation.

I know that the data and results of the study will only be published anonymously and confidentially to third parties. My questions have been answered satisfactorily.

[If applicable] I understand that film, photo, and video content or operation thereof will be used only for analysis and / or scientific presentations.

I voluntarily agree to take part in this study. While I reserve the right to terminate my participation in this study without giving a reason at any time.

Name participant:
………

Date: ……………………………….. Signature participant: ……………………………………………………….

To be completed by the executive researcher

I have given an spoken and written explanation of the study. I will answer remaining questions about the investigation into power. The participant will not suffer any adverse consequences in case of any early termination of participation in this study.

Name researcher: **Lukas Aldag**

Date: ………………………………….. Signature researcher: …………………………………………………….

Appendix B: Written instructions

April 2017

Participant Instruction

You will participate in an experiment that investigates how exactly people learn to execute movement sequences.

The experiment is composed of **6** blocks. After each part, you have a break of 4 minutes. You can do whatever you want during this break.

It is important for you to react as fast as possible, without making too many mistakes (less than 8%!).

The instructions will be displayed on the screen. If something is not clear please feel free to ask the experimenter.

The experiment will take about **3 hours** and will get you **3 SONA credits**. During the experiment you will be asked to fill in a short survey. Any remarks about the experiment can be made there.

Good luck with the experiment, and thanks for participating!

On behalf of,
Prof. W.B. Verwey
University of Twente

Appendix C: Color blindness test