The Effect of Recurrent Stimuli on Sequence Learning

Esmee van den Broeke

s1360159

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University of Twente

Faculty of Behavioral, Management, and Social Sciences

Bachelor of Psychology

Supervisors:

Prof. Dr. Ing. Willem Verwey,

Jonathan Barnhoorn, MSc.

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Abstract

The objective of the current study was to determine whether recurring stimuli influences sequence learning. A total of 24 participants took part in the study. They were divided into two groups. The groups performed a Discrete Sequence Production task, that consisted of a practice phase and a test phase. The analysis of the data revealed that there were no significant differences between the two groups with regard to the response times. Besides that, there was no relationship between the groups and the response times on Key. The conclusion that could be drawn from this is that recurring stimuli do not influence sequence learning. However, small differences in response times have been found, that, - even though they were not significant - could be an indication of an effect. Therefore, the study should be replicated with a larger participant sample to increase the results.

Samenvatting

Het doel van de studie was om te achterhalen of terugkerende stimuli sequentie leren beïnvloeden. In totaal deden 24 participanten mee aan de huidige studie, deze participanten werden onderverdeeld in twee groepen. De groepen voerden de Discrete Sequentie Productie taak uit, die bestond uit een oefenfase en een testfase. De analyse van de data liet zien dat er geen significante verschillen werden gevonden tussen de twee groepen wat betreft de reactietijden. Daarnaast, werd er geen relatie gevonden tussen de groepen en de reactietijden op Key. De conclusie die hieruit getrokken kan worden is dat terugkerende stimuli geen effect hebben op sequentie leren. Echter, er werden wel kleine verschillen in reactietijd gevonden, die, ook al waren ze niet significant, een indicatie zouden kunnen zijn voor een effect. Daarom zou de studie herhaald moeten worden met een grotere steekproef om de resultaten te vergroten.

1. Introduction

During our lifetime we learn numerous movements, like riding a bike, tying shoelaces or walking up and down the stairs. Automatization of these kinds of movements is important because it clears brain capacity for other processes, like preparing for behavior or performing concurrent tasks (Verwey, Groen & Wright, 2015). Automaticity is defined by Posner (1978) as being effortless, unconscious, and involuntary. A process is automatic if it can run without monitoring (Tzelgov, 1999) and it becomes automatic by practicing. Other elements that are involved in learning motor sequences will be described in the following paragraphs.

Besides practicing, attention is also important when learning these motor sequences (Nissen & Bullemer, 1987). Fisk and Sneider (1984) proposed that the amount of attention directed to stimuli determines how well people remember. Thus, when people direct enough attention towards a task they will remember it better. Fitts (1964) describes learning as a transfer from the attentive phase to the procedural phase. This implies that at first people focus their attention on what is being learned, later in the process learning becomes unconscious and shifts to the procedural phase.

Part of the procedural phase is procedural memory. Procedural memory is a memory system that is part of the non-declarative memory system, which is also referred to as implicit memory (Kessels, Eling, Ponds, Spikman & van Zandvoort, 2012). Procedural memory is comprised of skills and is the type of memory that helps us to do things unconsciously. Thus, at first people pay attention to the skill that is being learned. After practicing the skill, it becomes automatic and learning is shifted to the procedural phase.

Two forms of learning are involved in learning motor sequences, which are explicit and implicit learning of sequences. Explicit learning refers to acquiring knowledge and being aware of the knowledge and its effect (Rauch, et al., 1995). For instance, people know that they are learning to ride a bike and that the effect is that they can ride the bike by themselves. Implicit learning is defined by Reber (1993) as acquiring knowledge without awareness of the knowledge and its effect. For instance, in the example of learning to ride a bike, after a person had learned to ride a bike they perform movements automatically without being aware of those movements. These movements could be the process of getting on the bike, or something like steering, it does not require attention.

To study the process of sequential learning, researchers often use sequential key pressing tasks like the discrete sequence production (DSP) task (Verwey, 1999). In this kind of task, participants respond to stimuli by pressing keys assigned to the stimuli. Each response triggers the next stimulus. In the end, response times are compared. In the DSP task, the term substantial structural sequence knowledge is used when the participant has knowledge of the element order of the sequence and is able to verbalize this order. Learning is implicit when people are not aware of it and learning is explicit when people are aware. Thus, substantial structural sequence knowledge is explicit knowledge. In the DSP task, there is often an absence of substantial structural sequence knowledge (Kessels, Eling, Ponds, Spikman & van Zandvoort, 2012), but participants do seem to have implicit knowledge of the order. Participants learn the sequence order without awareness. Thus, the sequence will become automatic through implicit learning.

In the DSP task, Verwey (2003) distinguishes between a ‘reaction mode’ and a ‘chunking mode’. The ‘reaction mode’ is like the above mentioned attentive phase, where attention is required. When the participant practices, eventually the ‘chunking mode’ develops, which can be compared to the procedural phase. The chunking mode is a form of hierarchical control. Hierarchical coding is the process of placing behavior into units and organizing those into a hierarchy (Hard, Lozano & Tversky, 2008). Something is seen as a hierarchy when it has distinct levels of control (Rosenbaum, 2009). The hierarchy has goals and sub-goals and can be coded in a representation (Hard, Lozano & Tversky, 2008). When sequences can be described in a hierarchy, they are easier to learn (Rosenbaum, 2009). The chunking mode involves the use of motor chunks, which are representations that code short series of movements, that can be executed as a single response (Verwey, 1996, 1999). When forming a hierarchical order, the sequence is segmented into smaller representations (Rosenbaum, 2009). These smaller representations are usually linked to pre-existing units, which makes learning easier. There are multiple steps in the execution of a motor sequence, first, a motor chunk is selected and loaded into a motor buffer (Verwey, 2001). Second, a motor processor reads information from that buffer, so that the key presses can be executed one after the other. These key presses are represented by the motor chunk. Thus, by practicing the chunking mode develops which enables participants to respond faster, and this happens unconsciously and automatically.

The goal of the current study is to examine if the recurrence of a stimulus in a sequence creates the necessity for a hierarchical control mechanism. The expectation is that, when a recurring stimulus is introduced, the response time will be longer at the point of introduction. The element may be difficult to learn because, depending on its serial location, it is followed by different other elements. Therefore, there could be a spike in response time. The discrete sequence production task will be used to examine whether the response time of a participant is affected when there are three recurrent stimuli in the sequence. The participants are asked to react to the location of two series of six stimuli, two sequences. There is either a unique or ambiguous sequence. The unique sequences have no recurring stimuli, and the ambiguous sequences have recurring stimuli. There are two groups, the unique group, and the group with recurrent stimuli. There will be a practice phase before the actual test phase. There will also be a test, in between the practice phase and the test phase, that will examine the awareness of the participants. However, these data will not be reported in this thesis.

2. Method

2.2 Participants

Participants were gathered through the use of a website for recruitment of participants, through the researcher's own personal network, and by paying participants for their participation. Participation requirements were good vision, good motor skills. Also, the participants had to be no older than 35 years of age. A total of 24 people participated in the study. The mean age of the participants was 22, the minimum age was 19 and the maximum age was 32. Participants were divided into two groups of twelve participants each, named the Unique group and the Ambiguous3 group. The Unique group executed only unique sequences. The ambiguous groups executed ambiguous sequences with three recurring stimuli. The present study reports the control group and the Ambiguous3 group, which will be referred to as recurring stimulus group from now on. The study was approved by the ethics committee of the Faculty of Behavioral, Management, and Social Sciences of the University of Twente.

2.3 Apparatus

The experiment took place in two separate research cubicles. Efforts were made to perform the same amount of participants in each cubicle, in order to diminish the effects of the difference between the rooms. The experiment was conducted on a Dell Optiplex 9010 computer with Windows 7 Enterprise, in both cubicles. The computers were booted in a mode in which any unnecessary Windows services were shut off, to improve response time measurement accuracy. The stimuli were presented on a LG Flatron E2210 display, in both cubicles. In one cubicle a

Logitech Deluxe 250 Keyboard was used, and in the other cubicle a Dell KG212-B keyboard. The E-Prime© version 2.0 was used for presenting the task and collecting the data, and a separate test was used to measure awareness.

2.4 Tasks

DSP-task

The DSP-task consisted of two phases, the practice phase and the test phase. The participants used their ring, middle and index fingers, of both hands, on the D, F, G, and J, K, L keys. The sequences that were used in this task are presented in Appendix I. The sequences were balanced out in such a way that most of the fingers were used in each sequence. This was to reduce the discrepancy between the response times of the different fingers. Participants received their instruction and the task itself on the display, the task was instructed in Dutch. During the task, the squares on the display would turn green, after which the participants pressed the corresponding key on the keyboard. The stimuli are the locations of letters. When a wrong key was pressed an error message appeared, and then the next sequence would be presented. Each block was divided into one or multiple sub-blocks, and after each sub-block and completed block the response time and error rate was given.

Awareness-task

The Awareness task consisted of two tests with a short questionnaire afterwards. The task was presented in Dutch. The task tested for verbal and spatial sequential knowledge that could have been obtained during the practice phase. The spatial sequence knowledge was tested using a display of six squares in a row, like in the practice phase. Participants were requested to click the squares in the same order as the sequence, or they guessed. The verbal sequence knowledge was tested by six squares that were placed in a circle, each square contained one of the used letters. Participants were requested to click on the squares in the same order as the letters in the sequence, or they again guessed. Participants were not allowed to use or see the keyboard, which was held by the researcher. The instructions appeared on the screen.

After the awareness tasks, participants answered questions about the tasks. They were asked about the method that they had used to remember the sequences. The options were: “because I remembered the order of the letters on the keys”; “because I tapped the sequences on the table top”; “because I tapped the sequences in my mind”; “because I remembered the positions of the stimuli and keys”; and lastly, “I did not have a clue and just guessed”. The participants were also asked to indicate how sure they were about the order of the sequences they had given, the answers were: “very unsure”; “a little unsure”; “a little sure”; and “very sure”. Lastly, participants were asked if they had participated in a similar task in the last months or years. Alternative answers were: “no”; “yes, but I think both sequences were different”; “yes, and I think that one of both sequences was the same”; and lastly, “yes, and I think that both sequences were the same”.

2.5 Procedure

Before the experiment started the researchers prepared the cubicle. The lights were turned on and the blinds were almost all the way down. The participants were received in the general area of the experiment cubicles, and were led to one of the cubicles, where they were given instructions. They subsequently read and signed the informed consent. The participants were allowed to take their belongings into the cubicle, so they could eat or drink something during the breaks, and they were allowed to go to the bathroom in between blocks. The researcher started the program and entered the participant number, block number and age of the participant. After this the participant started the task. The researcher left the room and monitored the participant on the camera.

The participants performed practice block one till six, after each block the researcher restarted the program for the next block. The researcher also took a look at the response time and error rate, to verify that the experiment was going well. There were two repeating sequences of six stimuli in each block. As mentioned above, each block was divided into two sub-blocks, between those sub-block there was a 40 second break. Between each practice block there was a 180 second break. In the practice phase, there were 90 sequences per sub-block, and 180 sequences per block, which makes 540 per sequence and 1080 sequences in total during the practice phase.

After the sixth practice block the awareness test was administered. The participant was instructed and the researcher stayed in the room and covered the keyboard. After the awareness test the researcher started block seven, the test phase. The test phase, the seventh block of the task, consisted of one test block, divided into three sub-blocks, with a 40 second break between each sub-block. In the test phase there were 50 sequences per sub-block, and 150 sequences in total. The three sub-blocks of the test phase consisted of one block with the same two sequences as during the practice phase, another block with two new unique sequences, and one block with two new ambiguous sequences, and with three recurring stimuli.

When the participants were done they were thanked for their participation, and if they wanted they were given information about the experiment. Overall, the experiment took about two hours and fifteen minutes. During the experiment the researchers kept a record of the name of the participant, the time and date of the experiment, and any remarks about the participant or the circumstances of the experiment that could be of importance. They also kept track of the blocks that were completed.

3. Results

3.1 Practice Phase

Response Times

The response time in the practice phase was examined with a 2 (Group: recurrent stimuli vs. control) x 6 (Block: 1-6) x 6 (Key: 1-6) repeated measures ANOVA with Group as between-subject variable. It showed a main effects of Block, $F(5, 110) = 153.889$, $p < .001$, and Key, $F(5, 110) = 167.907$, $p < .001$. This means there is a difference in response times between the practice blocks and between the keys. This has been found in earlier studies and is to be expected as the participants were practicing the sequences.

There was, however, no main effect of Group, $F(1, 22) = 1.019$, $p = .32$. The mean response time of the recurring stimulus group was approximately 249 ms, while the mean response time of the Unique group was approximately 218 ms, making the mean difference between the groups 31 ms. The difference is also shown in figure 1, where it is apparent that the recurring stimulus group generally has longer response times per key than the control group.

The expectation was that there would be a Key x Group interaction. However, there was no Key x Group interaction, $F(5, 110) = .136$, $p = .984$, meaning that there is no difference in response times on different keys between groups. There was an Block x Key interaction, $F(25, 550) = 23.362$, $p < .001$, meaning there is a difference in response time on key presses per block. This result, however, is of no importance to this study.

In short, there is a significant difference found in response times between keys and between practice blocks, which was to be expected. There is a difference between the two groups regarding the response times, but this difference is not large enough to be significant. The expectation was that there would be a Key x Group interaction, but there was none. Therefore, with regard to the practice phase, the initial hypothesis can be rejected.

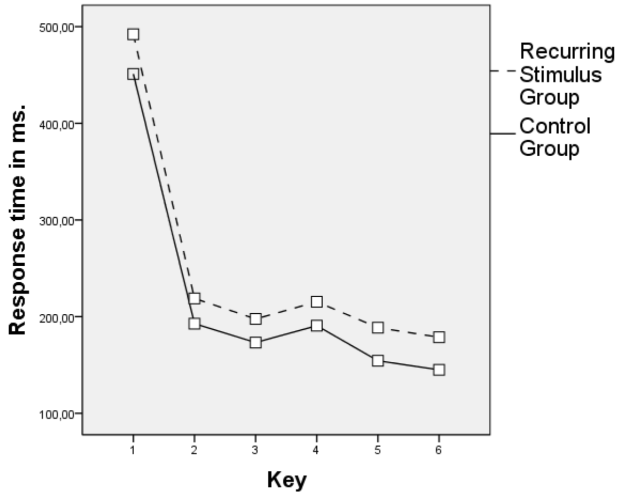

Figure 1 Mean response times (ms) per key per group of the practice phase

Error rate

The error rates for the practice phase were transformed by an arc sine transformation and after that analyzed with a repeated measures ANOVA, with the same design as the response times of the Practice Phase. No main effects were for Block, $F(5, 110) = .312$, p = .91, and also not for Group, $F(1, 22) = 0.17$, p = .68. This means that there was no significant difference between the blocks and between the two groups regarding error rates. However, there was a main effect for Key, $F(5,110) = 7{,}641$, p < .001, meaning that there was a difference in error rates between keys. Regarding the error percentages of Key, most errors were made on key 4 (2.2%), and the least errors were made on key 6 (0.7%). The error rates were used to check for the speed-accuracy tradeoff, this occurs when one can tradeoff accuracy for speed, and thus make more mistakes (Wickelgren, 1976). Because the error percentages are low, no speed-accuracy tradeoff has been found.

3.2 Test Phase

Response Times

The response time in the test phase was examined with a 2 (Group: unique vs. recurrent stimuli) x 3 (Condition: practiced sequences vs. new sequences unique vs. new sequences ambigue) x 6 (Key: 1-6) repeated measures ANOVA with Group as between-subject variable. It showed main effects of Condition, $F(2, 44) = 161.472$, p < .001, and Key, $F(5, 110) = 75.252$, p < .001. This means that there was a difference in response times between conditions and between keys. This was to be expected and is also represented in the mean response times of the conditions. The mean response time of the practiced sequence condition is approximately 182 ms, the mean response time of the unique new sequence condition is approximately 433 ms, and the means response time of the ambiguous new sequence condition is approximately 419 ms.

However, the analyses showed no main effect of Group, $F(1, 22) = .005$, $p = .946$. There was a relatively small difference in response time of approximately 3 ms. This small difference is also seen in figure 2, it shows that the response times of the two groups are almost the same in the beginning. At key 6 there is a larger difference in response time, where the recurring stimulus group has a longer response time than the control group.

The expectation was that there would be an interaction on Key x Group. However, there was no Key x Group interaction, $F(5, 110) = .165$, $p = .975$, meaning there is no difference in response times on different keys between groups. There was an Condition x Key interaction, $F(10, 220) = 14.407$, $p < .001$, meaning there is a difference in response time on key presses per condition. This result, however, is of no importance to this study.

In short, the expectation was that there would be a main effect of Group, however, this is not the case. There is a significant difference found in response times between keys and between conditions. This is the same as in the practice phase. The expectation was also that there would be a Key x Group interaction, but there was no interaction. Therefore, regarding the test phase, the initial hypothesis can be rejected.

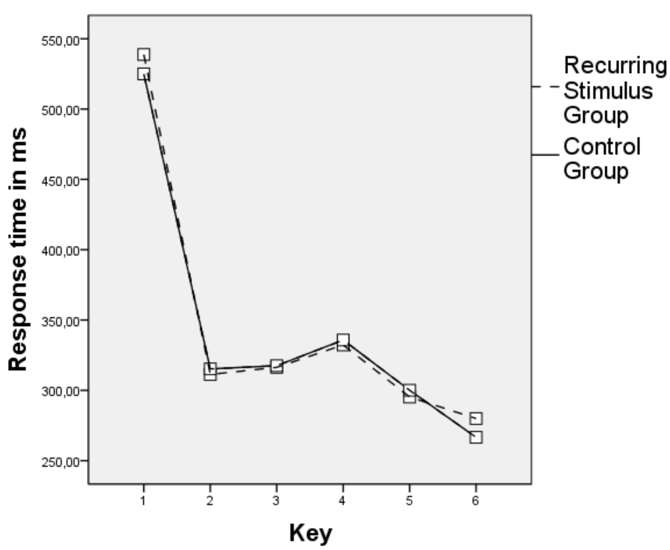

Figure 2 Mean response times (ms) per key per group of the test phase

Error Rate

The error rates for the test phase were transformed by an arc sine transformation and after that analyzed with a repeated measures ANOVA, with the same design as the response times of test phase. There was a main effect for Condition, $F(2, 44) = 9.584$, $p < .001$, and also for Key, $F(5, 110) = 2.795$, $p = .020$. This means that there was a difference between the conditions and between the keys regarding error rates. However, there was no main effect for Group, $F(1, 22) = 0.238$, $p = .630$. Regarding the error percentages of Conditions, most errors were made in the new unique sequence condition (2.5%), and the least error were made in the practiced sequence condition (1.3%). The new ambiguous sequence condition did not differ much with new unique sequence condition in error percentage (2.3%). Regarding the error means of Key, most errors were made on key 4 (2.2%), and the least errors were made on key 6 (.7%). Because the error percentages are low, no speed-accuracy tradeoff has been found. The difference between conditions can be explained by the introduction of new sequences.

4. Discussion

The objective of this study was to examine whether recurring stimuli influences sequential learning; this was tested with the discrete sequence production task. A total of 24 participants took part in the experiment. They were divided into two groups, a control group and a recurring stimulus group. The expectation was that there would be a difference between the two groups with regard to the response times, meaning that the control group was expected to have faster response times than the recurring stimulus group. Also, the expectation was that there would be relationship between the groups and the response times on Key.

The analyses of the experiment data revealed that there we no significant differences between the two groups in both the practice phase and the test phase. There was also no relationship between the groups and the response times on Key. The conclusion that could be drawn from these results is that recurring stimuli do not have an effect on sequence learning, thus, the hypothesis is rejected.

However, mean response times did show a difference between groups, in the practice phase (figure 1) as well as in the test phase (figure 2), even though it is small, especially in the test phase. As mentioned in the result section in the practice phase there is a difference of 31 ms between the two groups and in the test phase there is a difference of 3 ms. It could be that with a larger participant sample there would be more statistical power and then there could be a significant result. Future research could use a larger sample, or add data to the dataset used in this study.

Also, another result was found, which is seen in figure 1 and 2. It has become apparent that the group with the recurring stimuli has a longer response time of the entire sequence, compared to the control group. There are theories that state that systems operate in parallel when performing sequences, these include explicit- and implicit knowledge and procedural knowledge (Keele, Ivry, Mayr, Hazeltine & Heuer, 2003; Willingham, Goedert-Eschmann, 1999; Willingham, Salidis & Gabrieli, 2002). It could be that because of the recurring stimuli, one of the systems fails to operate. This could cause that the sequence, in its entirety, is performed slower.

In this study participants also performed an awareness task of which, however, the results were not used. The task tested for verbal and spatial, explicit, sequential knowledge that could have been obtained during the practice phase. Analyses of these results could show: whether the participants were aware of the order of the sequence by remembering the place of the stimuli on the screen; if they were aware of the order of the sequence by remembering which letter of the key board followed the previous one; or, if they were not aware at all. The awareness of the letter sequences could differ between groups, because the participants may differ in the method of learning. And it could be examined how the recurring stimuli influences awareness. Also, the differences between groups on the awareness task could be examined alongside response times. There is also evidence that explicit learning influences performance on motor tasks (Song, Marks, Howard & Howard, 2009). Especially when practicing for a longer period of time, which is more comparable to everyday life skill learning. Therefore, future research could analyze the awareness data, to examine these questions.

Research into this subject could shed light onto the process of learning certain movements. As mentioned in the introduction, automatization of certain movements is important because it clears brain capacity for other processes (Verwey, Groen & Wright, 2015). Thus, research into this subject will play a part in understanding sequence learning. And also, help develop rehabilitation techniques. And lastly, help to develop other studies by examining the limitations, and possibilities for further research.

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Appendix I

Table of sequences used in DSP task of the current study.

Unique	**Recurring Stimulus Group**
A0: KFGDJL	AR3: KFKGKD
B0: LGJFKD	BR3: LGLJLF
C0: DJKGLF	CR3: DJDKDG
D0: FKLJDG	DR3: FKFLFJ
E0: GLDKFJ	ER3: GLGDGK
F0: JDFLGK	FR3: JDJFJL