The effects of recurring stimuli on sequence learning in the discrete sequence production task

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Abstract

The present study examined the effect of recurring stimuli in a six keying sequence on learning of the sequence. In order to investigate the effect of recurring stimuli, one stimuli occurred twice during a six keying sequence in a Discrete Sequence Production (DSP) task. Previous research stated that ambiguous sequences are characterized by recurring stimuli which make it difficult to predict follow-up-elements of a sequence. Therefore, it was predicted that reaction times should increase as a consequence of the recurring stimuli which make follow-up-elements unpredictable for participants. Twenty-four students took part in the study. They were assigned to one of two groups. Both completed a DSP task with six practice blocks and one test block. While the first group learned unique keying sequences, the second group learned ambiguous keying sequences which contained recurring stimuli. In contrast with the predictions, the results did not show a difference between the two groups.

Samenvatting

Het huidige onderzoek was gericht op het effect van terugkerende stimuli in een toetsen sequentie op het leren van de sequentie. Een stimuli werd twee keer in een sequentie gebruikt om het effect van terugkerende stimuli in een sequentie te onderzoeken. Er werd gebruik gemaakt van de Discrete Sequence Production (DSP) task. Eerder onderzoek stelde dat ambigue sequenties door terugkerende stimuli gekenmerkt zijn. Deze maken het voorspellen van navolgende stimuli in de sequentie moeilijk. Op basis hiervan werd er voorspeld dat de reactie tijden in een ambigue sequentie zouden toenemen want de participanten zouden op basis van de terugkerende stimuli niet in staat kunnen zijn de navolgende stimuli te voorspellen. Vierentwintig studenten namen deel aan de studie. De studenten werden in twee groepen onderverdeeld. Beide groepen voerden een DSP task uit met zes oefen blokken en een test blok. De eerste groep leerde unieke toetsen sequenties. De tweede groep leerde ambigue toetsen sequenties met terugkerende stimuli. In tegenstelling tot de hypothese toonden de resultaten geen verschil tussen de twee groepen.

Introduction

In many piano pieces the same note appears repeatedly but is often followed by different note sequences throughout the song. Nevertheless, it seems that the pianists' fingers slide automatically over the piano keys. Although the same note precedes different other notes at different points, the pianist internalizes the series of notes. Considering this scenario, the present study faces the emerging question: What are the effects of recurring stimuli - e.g. a note which introduces different series of other notes during a song - on sequence learning? Recurring stimuli were implemented in a Discrete Sequence Production (DSP) task in order to answer this question.

Sequence Learning

According to Abrahamse, Jiménez, Verwey, and Clegg (2010) there is a long scientific tradition in studying the learning of sequences from the 1950s onwards. The learning of motor sequences makes us more flexible and enables us to prepare for actions while automatically executing an earlier motor sequence. A daily example would be typing a text on a cell phone or entering your PIN without thinking of it. Furthermore, learning motor sequences enables us to execute complex tasks like driving a car. Thus, learning sequences facilitates our daily live by making us more flexible and adaptable. Therefore, some researchers consider sequential behaviour as being fundamental to the human being (Abrahamse, Jiménez, Verwey & Clegg, 2010). Motor sequence learning mostly ends up in the ability of producing a rapid and accurate sequence of movements that requires only limited attention and effort (Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). Hence, the understanding of the cognitive mechanisms of sequence learning could enable a better training of perceptual motor tasks, like, for example, the improvement of driving skills or surgical interventions. Furthermore, it provides an opportunity to teach robots the learning of motor sequences. This could enable some progress concerning future technology.

All in all, this shows that humans are able to respond automatically to a plain stimulus with a learned sequence. A rather unchallenged question is how the learning of a sequence takes place when someone is confronted with a recurring stimulus which precedes different other stimuli in a sequence. According to Honda et al. (1998) an ambiguous sequence is characterized by the fact that an element cannot be predicted on the basis of the previous element, like the piano player who has to face a recurring note over the course of a song which is always followed by different other note sequences.

Over the decades scientists have developed various research paradigms like the DSP task in order to investigate the cognitive components of sequence learning. Destrebecqz and

Cleeremans (2001) state that a typical sequence learning situation is characterized by the repetition of visual stimulus sequences and corresponding motor responses. In the DSP task participants are asked to rest four to eight fingers on a keyboard. A screen in front of them displays the keys in the form of placeholders, e.g. squares (Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). Participants are instructed to press the corresponding key if the appropriate placeholder lights up. The DSP task involves an arbitrary order of responses which is not based on simple rule adaption. According to Rhodes, Bullock, Verwey, Averbeck and Page (2004), learning in the DSP tasks depends on noticing the first cue, which is the lighting of one placeholder – and ignoring the following ones. They claim that the DSP task is highly suitable for studying the segmentation of a sequence as well as the understanding of preparatory mechanisms (Rhodes et al., 2004). The present study created ambiguous stimulus sequences in the DSP task by using recurring stimuli in a six keying sequence, in order to investigate how these sequences are segmented and what effect they have on sequence learning.

Sequence Segmentation

Currently, the notion that elements in a sequence are organized in a hierarchically way offers the most sufficient explanation for sequence segmentation (Rosenbaum, 2009). Hierarchical control of motor sequences involves the segmentation of a sequence into smaller representations, called segments. These make contact with pre-existing higher level units which facilitate the learning of sequences because they contain familiar and already learned units. According to hierarchical learning, the higher the level the fewer elements are involved (Rosenbaum, 2009).

Usually, only sufficient practice can guarantee that a sequence is successfully learned even when the practitioner is not able to freely recall a given sequence. That is, the person is sometimes not able to verbally predict which stimulus follows another. Jiménez, Méndez and Cleeremans (1996) have shown that participants become sensitive to a repeating sequence of stimuli without actually being able to verbally predict them. It follows that sequence learning may be partly implicit. For example, Verwey and Abrahamse (2012) asked participants to complete a DSP task with a six keying sequence. They concluded that explicit knowledge of a sequence is not a necessary condition for learning.

Sequences can be structured using pauses between subgroups, the repetition of a fixed series of stimuli (e.g. JKLGFD JKLGFD) or by presenting the stimuli in an ambiguous way (e.g. KLJKGF). In an ambiguous sequence one stimulus recurs during the series (Cohen, Ivry & Keele, 1990). The following stimulus cannot be predicted on basis of the recurring stimulus, because this stimulus does not serve as a clear trigger for a unique follow-up-stimulus. Honda et al. (1998) argued that the main characteristic of recurring stimuli is that predictions concerning following stimuli are not possible. As a consequence, reaction times should be slower for stimuli which follow recurring stimuli because they are unpredictable, than when confronted with unique sequences. This is in line with Cleeremans and McClelland (1991), who asked participants to press as fast and accurately as they could on one of six different keys when a corresponding stimulus on a screen in front of them appeared. They were able to show that participants need significantly more time to react when exposed to unpredictable stimuli than if they were exposed to predictable stimuli.

Motor chunks

The segmentation of sequences into segments facilitates the learning of sequences and links the perception of a stimulus with a following response. Once motor chunks are formed – mental representations of the segments - they appear to be stable (Rhodes et al., 2004) and robust (Verwey, 2001). In addition, the first key press of a sequence is usually slower than the following key presses. If there are more segments developed in a sequence, the time between transition from one to the next segment is called concatenation point. It is marked by an increase in reaction time (Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). Thus, performing a keying sequence in a DSP task consists of three phases: initiation, execution and concatenation respectively.

Furthermore, some researchers state that the mental representations could be subdivided into spatial and motor codes (Shea, Kovacs & Panzer, 2011; Kovacs, Mühlbauer & Shea, 2009). Recently, Verwey, Shea and Wright (2015) argued for a cognitive framework for sequential motor behaviour (C-SMB), in which there are several processors which use different codes. These are independent but mainly interact with each other. To sum up, the development of motor chunks and the processing of them are fundamental to the understanding of the underlying cognitive mechanisms of sequence learning.

Key pressing is often used as an instrument to study sequence learning and the development of motor chunks (Shea, Kovaks & Panzer, 2011). Verwey and Abrahamse (2012) described motor chunks as memory representations that develop when practicing a given sequence of movements. The motor chunks are connected in a hierarchical structure (Rosenbaum, 2009) which facilitates the execution of the motor sequence as if it is a single motor response (Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). Verwey, Groen and Wright (2015) specified that due to the development of motor chunks the central processing of a task is reduced. This also decreases the reaction time. Furthermore, motor chunks could be seen as intrinsic representations of the executed movements which are task - and practice - dependent (Berniker, Franklin, Flanagan, Wolpert & Kording, 2014).

According to Rhodes et al. (2004) motor chunks have a limited capacity which is probably around four to five elements (Verwey, Shea & Wright, 2015). A possible explanation is that some sequences are simply too long to be stored in short term memory (Acuna et al., 2014). Therefore, more and smaller chunks are build which divide the sequence in segments which can be properly stored. Verwey and Eikelboom (2003) stated that longer sequences are already segmented after little practice. In line with the notion that motor chunks have a limited capacity, they outlined that each segment is represented by a single motor chunk. This is consistent with Verwey, Shea and Wright (2015) who explained that there is a slower key press in the middle of a longer sequence (> 5 elements) which they call the concatenation point. It shows that a longer sequence consists of independent segments (Rhodes, Bullock, Verwey, Averbeck & Page, 2004). Furthermore, Cohen, Ivry and Keele (1990) used an ambiguous structure (123132; 123132; 132312) in their study and come up with the essential idea that recurrent stimuli need to be parsed. They further explain that this in the end leads to a higher level description for each segment of the sequence, which serves as an additional cue for executing the sequence. This probably indicates that a six keying sequence, which contains a recurring stimulus, which is repeated two times in the sequence, is subdivided into several smaller motor chunks. Verwey and Eikelboom (2003) showed that these smaller motor chunks need to be under hierarchical control by controlling the order of the multiple motor chunks.

In conclusion, the first stimulus of a sequence in a DSP task serves as a cue to activate a certain motor chunk and the sequence is executed like a single motor response. The stimuli after the first one are usually ignored and not need to execute the sequence (Rhodes et al., 2004) because certain stimuli are expected to follow the first cue and the motor chunk is directly selected and carried out. When confronted with an ambiguous sequence it was predicted that this is not possible because neither the first nor the second time the recurrent stimulus occurs it can successfully trigger the follow-up-sequence element.

The present study

The aim of the present study was to determine what the effects of an ambiguous sequence are on learning the same sequence. The recurring stimuli in the sequences were followed by different stimuli (e.g. KFG KJL). Thus, the recurring stimuli (e.g. K) could not serve as a hint for follow-up-sequence elements. It was expected, that the ambiguous sequences were parsed (Cohen, Ivry & Keele, 1990) and that participants would develop smaller motor chunks for the ambiguous sequences. According to the concatenation point hypothesis, it was expected that reaction time would increase due to the transit of one motor chunk to the next. Thus, the concatenation point should be determined by the recurring stimulus. Second, it was predicted that participants need significantly more time for stimuli which follow the recurring stimulus, than for stimuli in a unique sequence.

Method

Participants

In total, 24 students took part in the study (14 female and 10 male). They were aged between 19 and 32 years. Sixteen students from the University of Twente participated in exchange for 3 course credits. Moreover, 8 participants were recruited via the social networks of the researchers. Four of them received a payment of 12 euro for participating. All participants signed an informed consent before the start of the experiment. No visual or motor restrictions were allowed. The ethics committee of the University of Twente approved the study.

Apparatus and setting

E-Prime© version 2.0 was used on a Dell Optiplex 9010 PC with Windows 7. EPrime was used for the DSP task and the awareness test. Stimuli were presented on a LG Flatron E2210 screen. Researchers used two rooms to conduct the experiment. Each room was equipped with a chair, desk and PC. The windows in both rooms were closed with blinds. In one room, participants used the Logitech Deluxe 250 Keyboard to accomplish the task. The other room was provided with a Dell KG212-B keyboard.

Task

The computer screen showed black outlines of six square placeholders on a white background. Each square was equivalent to one of the letters DFGJKL and arranged in the same spatial order as on the keyboard. The squares lit up in green and turned white again if the participant correctly pressed the corresponding key.

Experimental Conditions

Participants were assigned to one of three conditions on basis of their participant number which depended on their subscribed timeslot. The study was conducted in cooperation with another student who focused on recurring stimuli in which a letter was repeated three times. This report will not further outline the second study. The present study investigated the results of the control group and the group practicing with two recurring stimuli. During the practice phase, the control group (n=12) received two unique 6 keying sequences, e.g. KFGDJL. The recurring stimulus group (n=12) received two ambiguous 6 keying sequences during the practice phase. That is, one letter occurred twice per sequence during the practice phase, e.g. KFGKJL.

Procedure

Firstly, participants received a verbal instruction concerning the timespan of the experiment as well as subscribing the informed consent. After that the participants were brought to one of two research rooms in which they were observed by video cameras. The researcher started the computer in a mode in which there were no unnecessary background services.

The experiment started with an instruction on the screen after which participants conducted six practice blocks. The participants were instructed to put ring, middle and index finger of the left hand on the letters DFG and the corresponding fingers of the right hand on the letters JKL. In order to counteract finger specific effects of the participants, the order of keys was rotated across participants. For example, the sequence KFGDJL was presented to the first participant, while the sequence LGJFKD was presented to the second (Appendix A). Blocks were counterbalanced across the participants as well. Each practice block contained 180 sequences which were halfway divided by a 40 second pause into two subblocks (90 sequences). Error rates (in percentage) and mean execution time (in milliseconds) were shown to the participant after finishing a subblock as well as the whole block, which was followed by a 180-second-long pause. The remaining time was shown to the participants on the screen. At the end of each 180-second-pause the researcher entered the room in order to start the next block.

At the end of block six, participants performed an awareness test. The researcher covered the keyboard with a blank sheet in order to prevent participants from reproducing the sequence by looking at the keyboard. Participants were asked to reproduce the practiced sequences by clicking with the mouse on equivalent placeholders on the screen. Moreover, there were asked to reproduce the sequences by clicking on six squares, each containing a letter, which were spread over the screen. At the end, participants were asked how they managed to reproduce the sequences (a. by reminding the order of the letters on the keys b. by ticking the sequence with the fingers on the desk c. by ticking the sequence in thought d. by reminding the position of the squares and keys e. I had no idea and just guess something). In addition, participants were asked how sure they were about their decision (very sure – a little bit sure – a little bit unsure – very unsure) and if they participated in a similar experiment in the last years. This report will not further examine the results of the awareness test.

Block seven was the test block and included three 45-trial subblocks. Two 40-seconds-pauses separated the three blocks during which again error rate and mean execution time was shown to the participants. During the test phase, each group conducted two familiar sequences and four new sequences. The four new sequences contained two unique sequences and two ambiguous sequences. The control group was divided into two groups of six participants each. The first half received ambiguous sequences with three repetitions of a letter, the second half performed on ambiguous sequences with two repetitions.

Results

Practice blocks

A repeated measures ANOVA was run on the practice blocks (1-6) with a 2 (Control Group vs Recurring Stimulus Group) x 6 (Blocks) x 6 (Keys) design on response times with group as between-subject variable. In line with former studies key, $F(5, 110)=205.82$, $p < 0.001$, and block, $F(5, 110)=239.06$, $p < 0.001$, showed a main effect. However, no significant interaction was found between key and group, $F(5,110)=1.67$, $p > 0.05$. In addition, there was no significant main effect of group, $F(1,22)=2.83$, $p > 0.05$. Figure 1 shows mean reaction times of the keys 1 to 6 of the control group and the recurring stimulus group across block 1 to 6.

An ANOVA with the same design was used to analyse the error rates of the practice blocks. Beforehand, the error rates were arcsin transformed. A main effect was found for key, $F(5, 110)=11.13$, $p < 0.001$, but not for block, $F(5, 110)=0.69$, $p > 0.05$. No significant interaction of key and group was found, $F(5,110)=1.89$, $p > 0.05$. Moreover, no main effect of group was found, $F(1, 22)=0.34$, $p > 0.05$.

The average error percentage for the first key presses in the recurring stimuli group was 0,8 %. For both, the second and third key presses, average error percentages were 1.6 %. Finally, more errors were made at the fourth key presses, 2.7 %. The average error percentage of the fifth key presses was 2.0 % and 1.4 % for the sixth key presses. The control group had a 0.7 % average error percentage for the first key presses. The second key presses had a 1.2 % average error percentage. For the third key presses error percentages amounted 2.4 %. For the fourth key presses, average error percentage was 2.1 %. The average error percentage of the fifth key presses was 1.9 % and 0.6 % for the sixth key presses.

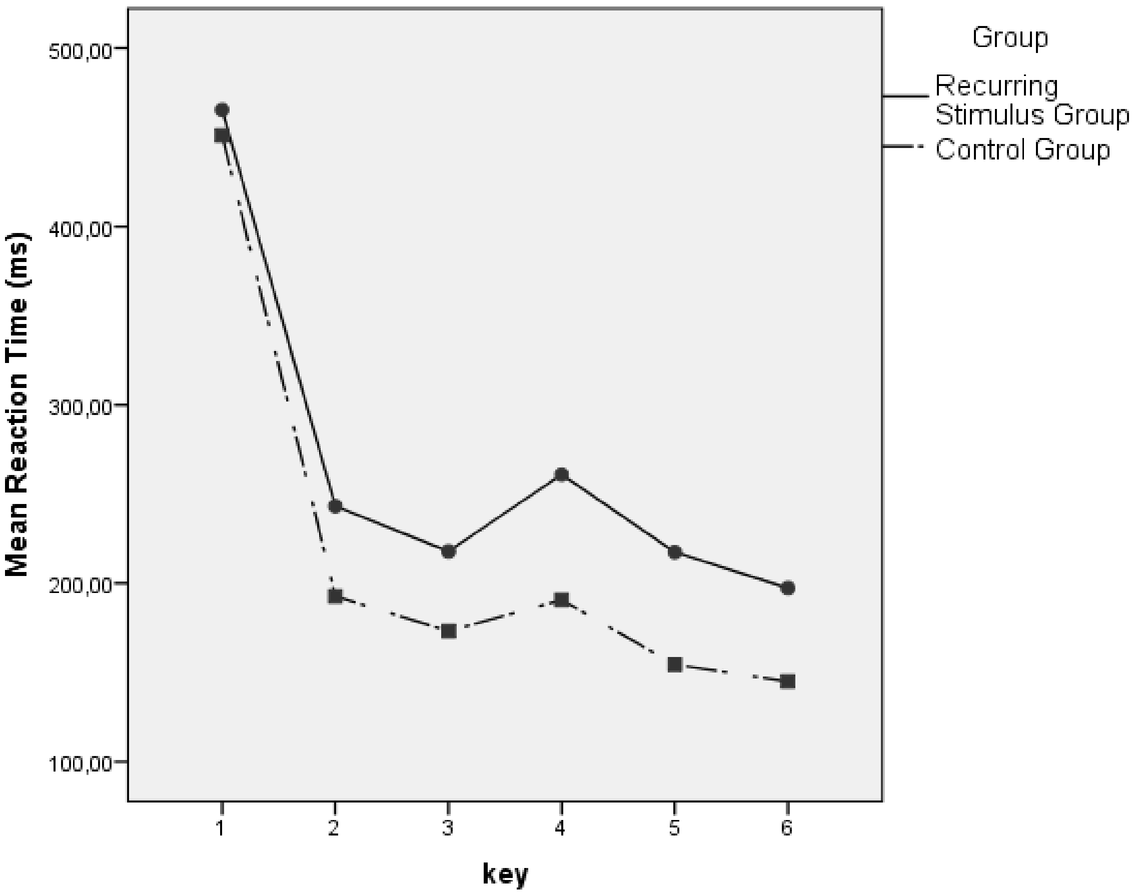

Figure 1. *Mean reaction times (ms) of the keys 1 to 6 during the practice blocks 1 to 6 between the Control Group and the Recurring Stimulus Group.*

Test block

A repeated measures ANOVA was run on test block 7, using a 2 (Control Group vs Recurring Stimulus Group) x 3 (Condition same sequence vs new sequence unique vs new sequence (as practiced for recurring stimulus group and new for control group)) x 6 (Key) design on response times with group as between-subject variable. Main effects for key, $F(5,110)=91.18$, $p < 0.001$, and condition, $F(5,110)=226.18$, $p < 0.001$, were found. Contrary to the prediction, no significant interaction between key and group was found, $F(5, 110)=1.11$, $p > 0.05$. There was no significant main effect of group, $F(1, 22)=1.90$, $p > 0.05$. Reaction times of the Control Group and Recurring Stimulus Group during block 7 are shown in figure 2.

An ANOVA with the same design was run on the arcsin transformed error rates of the seventh block. Significant main effects of condition, $F(5,110)=8.77$, $p=0.001$, and key, $F(5,110)=3.22)$, $p < 0.01$, were found. No significant interaction between key and group was found, $F(5,110)=1.13$, $p > 0.05$. In addition, there was no significant main effect of group,

$F(1, 22)=2.16$, $p > 0.05$.

The average error percentage for the first key presses in the recurring stimuli group was 3.1 %. For the second key presses, average error percentage was 3.0 % and for the third key presses 2.0 %. Finally, more errors were made at the fourth key presses, 4.7 %. The average error percentage of the fifth key presses was 2.6 % and 1.6 % for the sixth key presses. The control group had a 1.6 % average error percentage for the first key presses. The second and third key presses both error percentages amounted 2.2 %. For the fourth key presses, average error percentage was 2.5 %. The average error percentage of the fifth key presses was 2.4 % and 1.7 % for the sixth key presses.

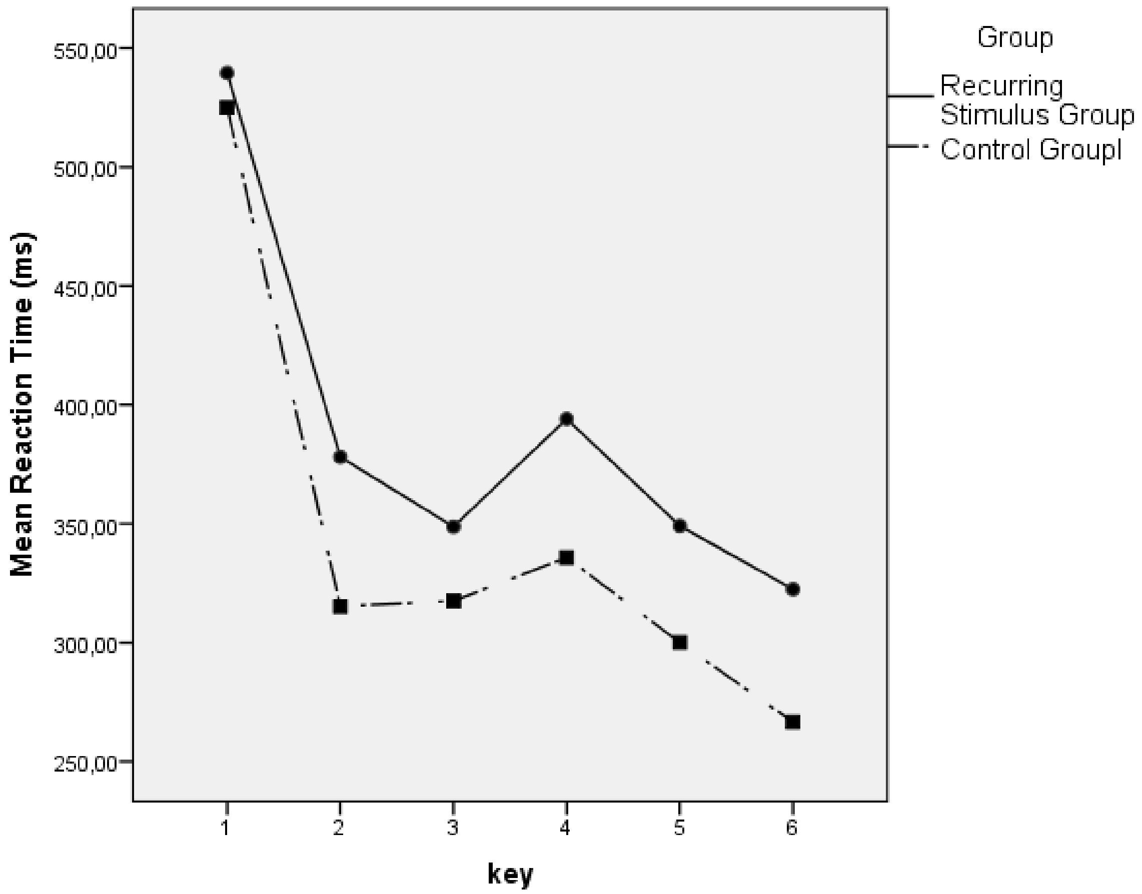

Figure 2. *Mean reaction times (ms) of keys 1 to 6 during the test block 7 between the Control Group and the Recurring Stimulus Group.*

Discussion

The main aim of this study was to investigate whether reaction times may increase in an ambiguous six keying sequence which includes recurring stimuli. Results do not confirm the hypothesis that participants would need significant more time to react to stimuli in ambiguous sequences, which contain recurring stimuli, than for unique sequences. It seems that participants were able to learn the ambiguous sequences as well as the unique sequences.

According to Cohen, Ivry and Keele (1990), a simple linear association is not possible in an ambiguous sequence because no unique associations between the elements of the sequence could be made. Instead, it was hypothesized that the ambiguous sequences are parsed into smaller motor chunks. The results showed that the concatenation point was probably on the fourth element in the ambiguous as well as in the unique sequence. Thus, unique and ambiguous sequences seemed to be parsed into two segments by the participants. This is in line with Cohen, Ivry and Keele (1990), because it could be that the ambiguous sequences were parsed on the basis of the recurring stimuli, which were placed on the first and fourth key of the sequences. Nevertheless, unique and ambiguous sequences were segmented in the same way. Thus, it could not be claimed with certainty that the ambiguous sequences were segmented on the basis of the recurring stimuli. Further research is needed, in which e.g. the position of the recurring stimuli in keying sequences is changed, in order to investigate if recurring stimuli influence the segmentation of ambiguous sequences.

In contrast with Cleeremans and McClelland (1991), the results did not confirm that the participants need significant more time for unpredictable, i.e. the follow-up elements of the recurring stimuli, than for predictable stimuli, i.e. the unique sequences.

Furthermore, humans are constantly looking for recurrent regularities in order to facilitate learning and problem solving (Bruner, Wallach & Galanter, 1959). This process is described by recognizing a pattern in e.g. a keying sequence. The ambiguous sequences were characterized by two recurring stimuli which appeared always on the first and fourth point of the six keying sequence. On the one hand, the recurring stimuli could make it difficult to predict the follow-up-elements of the sequence. But on the other hand, the recurring stimuli structured the sequences by dividing it into two parts. By recognizing this pattern, it was probably possible for the participants to learn the ambiguous sequences better than it was expected beforehand.

Although there was no significant difference between the two groups, the results indicated that reaction times of the recurring stimulus group seemed to be slower than the reaction times of the control group. Thus, it is recommended to arrange a follow-up study with more participants in order to make a probably present difference between unique and ambiguous sequence learning visible.

In the end, the results did not confirm that there is a significant difference between the reaction times in ambiguous and unique keying sequences. Nevertheless, the results imply that further research of ambiguous sequences could be interesting as far as we still do not know much about this topic. The understanding of ambiguous sequence learning could then add important knowledge to the development of cognitive models, which could be used e.g. to teach robots the learning of motor sequences.

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Appendix

Appendix A: Table with sequences

Unique	Ambiguous2 (2x3)	Ambiguous3 (3x2)
A0: KFGDJL	AR2: KFGKJL (2x K)	AR3: KFKGKD (3x K)
B0: LGJFKD	BR2: LGJLKD	BR3: LGLJLF
C0: DJKGLF	CR2: DJKDLF	CR3: DJDKDG
D0: FKLJDG	D2R: FKLFDG	DR3: FKFLFJ
E0: GLDKFJ	ER2: GLDGFJ	ER3: GLGDGK
F0: JDFLGK	FR2: JDFJGK	FR3: JDJFJL