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The role of stimulus location when executing highly practiced movement sequences

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Abstract

This study was conducted to analyse the effects of the location and identity of a stimulus when executing a discrete sequence production task. During the experiment, 24 participants practiced two sequences of seven keys which corresponded to four letters on the keyboard. The stimuli given to the participant were either in one placeholder or four placeholders. To analyse the effect of the location of the stimuli, the letters either corresponded with its relative location on the keyboard or did not correspond with that location. To analyse the effect of the identity of the letter itself, the stimuli were manipulated by presenting corresponding letters, non-corresponding letters or neutral stimuli (X's). Results indicated that the reaction times decreased when the location of the stimuli corresponded with the relative location on the keyboard. The reaction times were also shorter when the letter corresponded with the letter on the keyboard although this effect was not significant. This study concludes that the Stimulus-Response channel is still being used in sequence execution and depends mostly on the location feature of the stimulus which triggered the response.

General introduction

Basic activities like driving a car or signing a document with your signature are learned activities that require little attention. This motor sequence execution consists of several phases and is described by various models and theories. Research in motor automaticity has been a relevant topic for years now. Although we are hardly aware of this ability in daily life, it is indispensable. Executing a series of movements while little attention is needed is one of the skills that require the cooperation of multiple functions of the brain. Because the knowledge about the brain is limited, current insights in the functioning of its structures are uncertain. Over the years however, a lot of tools have been created to study these processes. These studies have contributed significantly to the progression of the knowledge about motor automaticity. In the present study motor automaticity was analysed by means of the Discrete Sequence Production (DSP) task. In this task, participants produce sequences by responding to successive stimuli that are mapped to response keys. As the participant performs the task more often the processing of each individual stimulus changes to producing the whole sequence by only processing the first stimulus (S1) and having little notice of later stimuli (Verwey, 1999). A cognitive model that accounts for the capacity to develop this skill is the Dual Processor Model (DPM). Previous research has shown that the Simon effect can be observed in sequence learning. The Simon effect involves the finding that reaction times (RT) are faster when the stimulus occurs in the same relative location as the response (Simon & Wolf, 1963). In the present study the role of the location and the content of the stimuli for the Simon effect are separately studied in a DSP task. By displaying neutral stimuli instead of key-specific stimuli after the practice phase, the influence of its location can be examined. A neutral stimulus refers to a stimulus that does not elicit specific associations for a subsequent response in the DSP task. A key-specific stimulus refers to a stimulus that does elicit a specific association for a subsequent response.

The Dual Processor Model

The Dual Processor Model (DPM) states that a cognitive processor and a motor processor are responsible for skill in executing discrete movement sequences. The cognitive processor translates every stimulus that is presented into the associated response after which it prompts the motor processor to execute this response. A motor buffer (assumed to be part of working memory) may also be used to load, one by one and before execution, a (limited) number of individual responses in case of novel but explicitly known sequences. When repeatedly executing short series of movements that are close in temporal proximity, it is assumed that these series will gradually integrate into a single representation (a motor chunk). These motor chunks allow the cognitive processor to select and load the chunk from long term memory in a single processing step into the motor buffer which results in a single response per motor chunk (Verwey, 1999). By loading the motor buffer, the motor processor is triggered to start reading the codes for the individual movements from the motor buffer and to execute the movement series in a relatively autonomous manner. The sequence skill is made up by the rapidity with which familiar sequences can be selected and executed through this buffer-mediated process. The sequential movement skills can be considered automatic, according to the DPM, to a certain extent. First little cognitive processor involvement is required when motor chunks are executed by the relatively autonomous motor processor. Second, the contribution of the cognitive processor may even be further reduced (with practice) as whole motor chunks may become triggered by external stimuli as if they involve prepared reflexes (Hommel, 2000).

The Discrete Sequence Production task

To study motor sequence learning using the DSP task it is needed to have an overview of the DSP task. In the DSP task, a participant has four to eight fingers resting on the designated keys of a keyboard. On the screen, a similar number of placeholders can be seen that correspond with spatially compatible keys on the keyboard. When a placeholder lights up, the participant presses the (spatially) corresponding key on the keyboard after which the next stimulus will be presented. The distinctive DSP sequence consists of two fixed series of three to seven stimuli. These series are executed in two equally long key-press sequences. The sequences are in a random order. With practice, these sequences can be interpreted as a single 2-choice task (with responses consisting of two multiple key sequences) instead of a task with two alternative series of responses. The execution thus changes from two series of, for example, 6-choice tasks to a single 2-choice task in which a whole 6-key sequence consists of a single response (Abrahamse, Ruitenberg, De Kleine & Verwey, 2013). The DSP task starts with a practice phase in which both sequences are repeated for 500 to 1000 times. In this phase, the motor chunks are created. A motor chunk represents a limited number of responses (depending on the number of stimuli in a sequence) that can be selected and executed as if they are a single response in a control hierarchy (Book, 1908; Miller et al., 1960; Pew, 1966; Newell and Rosenbloom, 1981; Verwey, 1996).

When the DSP task is executed, several phenomena can be observed. According to Abrahamse, Ruitenberg, De Kleine and Verwey (2013) the keying sequence can be divided into three distinct processing phases which can be derived from RTs. The first phase is the initation phase which involves the RT to S1. This slower RT on S1 is assumed to involve the preparation and selection of the sequence (Verwey, 1999). The key-presses that follow the initation are typically fast (the RTs are sometimes below 100 ms). Because the preparation and selection already occurred during the initation phase, these reactions only involve execution processes. Therefore these key-presses are referred to as the execution key-presses.

Halfway through the sequence (in sequences longer than four key-presses) the RT is longer again. This effect can be attributed to the segmentation of a sequence in several chunks (a 6-key sequence as 2 or more segments). This segmentation is referred to as concatenation. Concatenation ensures the smooth execution of distinct motor chunks in a sequence. This response is slower because it is assumed to represent the transition from one motor chunk to the other.

According to Verwey (2003), sequencing performance in the DSP task involves (at least) two execution modes. At the start of the task, the participants use each key-specific stimulus to select a response which is called the reaction mode. When performing a discrete sequence repeatedly, participants learn the order of responses and stimuli and start performing the sequence (or parts of it) in response to just S1. In this chunking mode the subsequent stimuli can be ignored. Key-specific stimuli are no longer needed. In recent studies, an associative mode in which the discrete keying sequence can be executed is found. This mode is an intermediate mode in which successive reactions are primed by the preceding responses but still require stimulus processing for the execution. This mode, which is still based on external guidance by movement-specific stimuli, would only emerge if the (much faster) chunking mode is not used (Abrahamse, Ruitenberg, De Kleine & Verwey, 2013). In the present study, the reaction mode and chunking mode will be explained by the use of the Stimulus-Response channel and the Response-Response associations. In an unknown sequence, a given stimulus triggers a single response. In this process, the cognitive processor selects every single reaction and loads every response into the motor buffer. The Stimulus-Response channel is used in this reaction mode because every single stimulus triggers one single response. After practicing a sequence, motor chunks are made which makes it possible for the cognitive processor to retrieve a motor chunk from long-term memory and load this whole chunk into the motor buffer. The use of this chunking mode is faster because it enables the possibility of Response-Response associations. This means that there is no stimulus needed to trigger the next response in the sequence. The provision of S1 is enough to execute a whole chunk of responses. The Response-Response associations are thus used instead of the Stimulus-Response channel. In addition to the reaction mode and chunking mode, another mode has been proposed by Verwey, Shea and Wright (2015). This Central-symbolic mode is more flexible when it comes to sequence learning. This mode implies that a movement sequence can be represented in verbal and spatial ways. This mode uses a central processor instead of a motor processor and the representation of how a sequence is learned are described in the six assumptions in '*A cognitive framework for explaining serial processing and sequence execution strategies*' by Verwey, Shea and Wright (2015).

The Simon task

While in the DSP task the focus is on sequence learning, in the Simon Task the focus is on attention. This attention could play a role in the study on motor automaticity. In a standard Simon task, stimuli are presented on the left side or on the right side of the screen. The participant is told to press a key on the left side of the keyboard with their left hand when a certain stimulus (for example an 'A') is presented at either the left or right side of the screen. The participant should press a key on the right side of the keyboard when another stimulus (for example a 'B') is presented on either the left side or right side of the screen (Simon & Wolf, 1963). The participant should thus focus on the letter (whether it is an 'A' or a 'B') and ignore its spatial location (on the left side or right side). The Simon effect refers to the finding that the RT is usually shorter when the stimulus is presented in the same relative location as the response, even though the stimulus location is irrelevant to the task. In terms of the example above, the RT should be faster when an 'A' is presented on the left side of the screen than on the right side even when the location of the stimulus is irrelevant to the task. According to Simon (1969), this effect can be explained by 'postulating a natural tendency to react toward the source of stimulation'.

Present experiment

The presence of the Simon effect in, for example, the research of Welch and Seitz (2013) has shown that the stimulus location is being processed even when this location is irrelevant to the task. The question whether the location or the letter of the stimulus is important in executing a learned sequence can be studied by adjusting the DSP task in different conditions. After the practice phase it is expected that motor chunks are formed with the use of the DSP task. By using neutral letters (like an 'X') and use a single location the influence of the stimulus features (letter or location) can be studied. To study the influence of the letter and the location, a clear distinction will be made in the different conditions. The first two conditions will be referred to as LocLetNC and LocLetC because the influence of both the location and the letter will be tested in a non-corresponding and corresponding condition. The LocLet conditions will be compared to each other to determine whether there is a Simon effect in this DSP task. The presence of a Simon effect would indicate that the Stimulus-Response channel is still used after practice in a DSP task. The second two conditions will be referred to as LocNC and LocC because the influence of the stimulus location will be tested in a non-corresponding and corresponding condition. The Loc conditions will be compared to each other to determine the influence of the stimulus location in this DSP task. Shorter RTs in LocC would imply that the Stimulus-Response channel is used and dependent on the location of the stimulus. The fifth condition will be referred to as Neu because it will test the influence of only neutral letters after S1. The last two conditions will be referred to as LetNC and LetC because the influence of the letter will be tested in a non-corresponding and corresponding condition. The Let conditions will be compared to each other to determine the influence of the letter in a DSP task. Shorter RTs in LetC would imply that the Stimulus-Response channel is used and dependent on the letter. When comparing these conditions with each other, the questions can be answered whether there is a Simon effect and whether this effect is induced by the location or the letter. The first hypothesis that is derived from these questions is: The Simon effect is induced via the location of the stimulus. The second hypothesis is: The Simon effect is induced via the letter.

Method

Participants

A total of 24 participants were included in this study. These participants consisted of 18 women and 6 men. The mean age of the participants was 19.5 years with a standard deviation of 1.8. The age of the participants varied from 18 to 25 years old. Among these participants, 20 were German, one was Dutch and three had another nationality. All participants were students of the University of Twente from the study programmes of Psychology and Communication Sciences. The participants were motivated to take part in the experiment by granting them credits. All participants were right-handed. The ethical committee of the Faculty of Behavioural, Management and Social sciences from the University of Twente approved the study.

Materials

The program that registered and presented the stimuli was running on a Dell Optiplex 750 computer. The experiment was made with a programming tool named e-Prime 2.0. The computer made use of Windows 10 Enterprise (64 bit) and had a Samsung 250 GB hard drive. The monitor was an AOC Freesync with the capacity to refresh the whole screen 144 times per second (144Hz). Access to the internet was blocked to improve the measurements of response time and avoid interruptions like updates or advertisements and unnecessary background services. The camera that observed the participant to see if the block was finished was a GoPro. The experiment took place in the BMS lab at the University of Twente. The Cubicle room had a desk with the computer (with a usb keyboard and mouse) and a chair. The sunblind was closed to three quarters of the window to prevent distraction from the environment. An informed consent was filled in, before taking part in the experiment, to inform the participant with the terms and conditions of the experiment.

Task

The task consisted of a modified DSP task. The participants responded to the given stimuli, this was tracked by the RT between onset of the stimulus and the actual press of a key on the keyboard. The keys 'C', 'V', 'B' and 'N' on the keyboard corresponded with the given stimuli 'E', 'U', 'R' and 'O' on the screen. The stimuli were given in either one or four placeholders on the screen (2cm x 2cm blank squares), presented in a horizontal row in the four placeholder task. After the participant pressed a key, the next stimulus was shown in one of the squares (or in the same square when the one placeholder task was shown). The word 'error' appeared above the placeholders when the wrong key was pressed.

Practice phase

Block 1 was a learning block in which the stimuli were mapped with the keys on the keyboard. This block consisted of random sequence orders shown in 50 trials in one central placeholder. In the first subblock the letters of 'EURO' were displayed to connect them with the 'CVBN' keys. The two subblocks added up to a total of 100 sequences in a random order with a 40 seconds pause in between subblocks.

Blocks 2 to 6 were made up of the practice phase. This phase had to ensure that the participants were familiar with the two 7-key sequences. In this phase the motor chunks were developed. In block 2 to 6 the practice phase consisted of the two fixed sequences (50 trials per block) shown over the four placeholders making a total of 250 trials per sequence across blocks 2 to 6. These sequences were counterbalanced over the 24 participants. The two sequences were chosen from four different orders of the CVBN letters in a counterbalanced way (see appendix 2). In 25% of the trials, the location of the stimulus corresponded with the location of the key on the keyboard (for example C with an E on the most left placeholder). After each subblock the percentage of errors and the average RT was shown to the participant. After each block (consisting of two subblocks) there was a four minute break before the experimenter started the next block. A pause of 500ms to 2000ms was included in the practice phase between the fourth response and the fifth stimulus. This pause was implemented to make sure that the participants segmented the sequence at this point and thus divided the sequence into two motor chunks.

Test phase

The test phase (Block 7) was made up of four subblocks which were executed without pauses during each sequence. In the first two subblocks there were four placeholders. In one subblock (LocLetNC and LocLetC conditions), there were 0% conflicting letters and 25% corresponding locations. In the other subblock (LocNC and LocC conditions), the stimuli after S1 were neutral (an 'X' instead of letters) and there were 25% corresponding locations. The order of the first two subblocks was counterbalanced.

In the third and fourth subblock only one placeholder was used. The third subblock (LetNC and LetC conditions) consisted of 25% conflicting letters (so 75% of S2-S7 were other letters of EURO and should be ignored). The fourth subblock (Neu condition) consisted of neutral letters (X's) after the first S1.

Awareness test

After completing the test phase (block 7) the participants filled in an awareness test. In this awareness test the participant could only click with the left mouse button and the keyboard was covered with a sheet of paper to prevent seeing the response keys. The experimenter stayed in the room to make sure that the sheet was not removed. In one part of the awareness test, the participants were instructed to click the two sequences in four (blank) square boxes which were lined up next to each other to assess spatial sequence knowledge. In another part the participant had to click the right sequences when there were four squares with either the letters C, V, B and N or E, U, R and O in a rhombus shape divided over the screen to assess two forms of verbal sequence knowledge. These three tasks were in a random order for each participant. After these tasks, the participants had to state how sure they were about the sequence they reproduced and how they reproduced it. An example of an option was 'I tapped the sequence on the desk'. The scores of the awareness test will not be explicitly reported in this study.

Procedure

After filling in the informed consent, the practice phase started. The participants were given a brief, spoken and written instruction (see appendix 1) and were asked to put their cell phones off. The experimenter started each next block manually when the previous block was finished (as seen via the monitoring camera). The experiment was made up of seven blocks which took on average 15 minutes to finish. Considering that the test phase (block 7) took longer to finish and there was an awareness test after the test phase, the whole experiment took three hours on average to complete. The participants held the fingers of their left hand on the keyboard in the following order: pinky-C, ring finger-V, middle finger-B and index finger-N. All participants got different sequences in the DSP task. This randomization of assigned sequences was ensured by four counterbalanced orders which were divided over the 24 participants. The four sequences (see appendix 2) were divided in two groups to ensure that two sequences could be assigned per participant. By counterbalancing the fingers of each participant over the sequential positions of the sequence, finger-specific effects are ruled out. All fingers contribute equally to the RTs at each sequential position.

Results

Practice phase

The keying skill, which had developed in the practice phase, was analysed with a 5 (Block 2-6) x 2 (Corresponding vs. non corresponding location) x 6 (Key 2-7) ANOVA to determine the differences in RT. The data of block 1 is not analysed because this block was meant to get familiar with the keys and had no added value to the results. The RT of the participants decreased across the successive blocks, $F(4,92)= 45.14$, $p<.001$, which could indicate that motor chunks had developed. In figure 1 the decrease of RTs along the successive blocks can be seen.

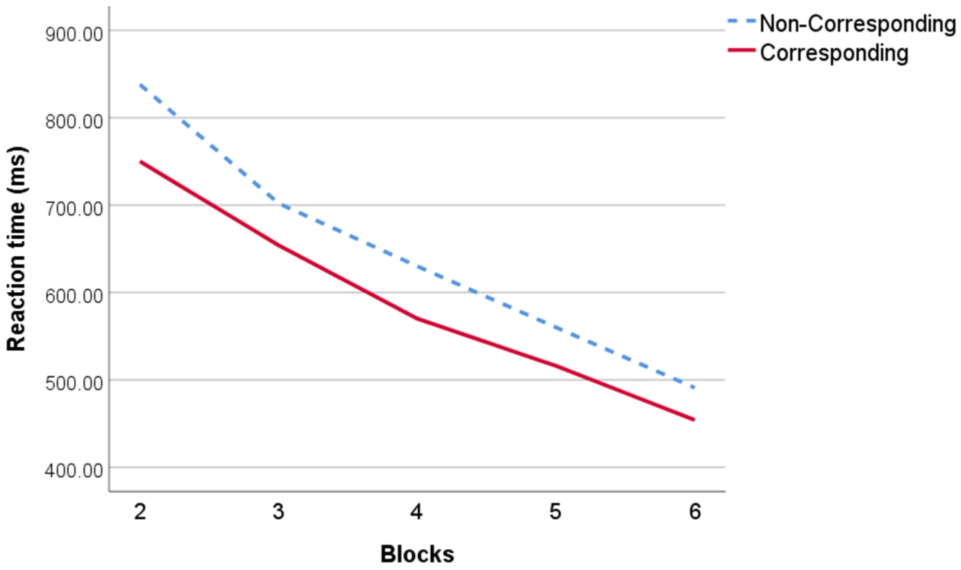

Figure 1: Average reaction times (in ms) per block in the practice phase for non-corresponding and corresponding response locations.

Furthermore, the average RTs of the trials in which the location of the stimulus corresponded with the location of the key on the keyboard, were faster than the ones which did not correspond (non-corresponding: 644ms, corresponding: 589ms), $F(1,23)= 59.75$, $p<.001$. These results are in line with the theory of the previously indicated Simon effect. The effect of Key was also significant, $F(6,138)= 32.96$, $p=<.001$ indicating that there were differences in RTs among the keys executed. The interaction of Block x Key $F(20,460)= 3.15$, $p<.001$ indicated that the differences between keys became shorter as the number of successive blocks increased.

For the errors in the test phase the same design, 5 (Blocks 2-6) x 2 (Corresponding vs. non corresponding location) x 6 (Key 2-7), was used like with the RTs in the test phase. This repeated measures analysis of variance (ANOVA) was executed after an arcsine transformation of the error proportions (because the data was not normal distributed). These errors were analysed to rule out the option that the observed RT effects are due to a speed-accuracy trade-off. The effect for Block was significant $F(4,92)=5.87$, $p<.001$, which indicates that there were differences in percentage of errors among the blocks executed. The errors differed from 2.6% on Block 2, to 3% on Block 6. The effect for Key $F(6,138)=4.68$, $p<.001$ was significant and indicated that there was a difference in percentage of error among the keys executed. The percentage of errors differed from 3.0% on Key 2, to 3.1% on Key 6. The main effect of Correspondence $F(1,23)=85.22$, $p<.001$ was significant and indicated that there was a difference in percentage of errors when the location of the letter corresponded with the location of the key on the keyboard. The participants indeed made more errors when the location was non-corresponding (3.24% vs. 2.32%), $F(1,5)=452.16$, $p<.001$. The interaction of Block x Correspondence $F(4,92)=4.82$, $p=.001$ indicated that there was a significant difference in percentage of errors for the non-corresponding and corresponding conditions as the number of successive blocks increased. The percentage of error differed from 3.3% for the non-corresponding condition in Block 2 and 6, to 1.9% and 2.7% for the corresponding condition in Block 2 and 6. The interaction of Correspondence x Key $F(4,115)=2.53$, $p=.033$ indicated a difference in percentage of errors for the non-corresponding and corresponding conditions among the keys.

Test phase

Three participants (9, 17, 24) were excluded from the data of the test phase because they could not execute the DSP task in the Loc, Neu and Let conditions. They felt unable to carry out these tasks even after an oral explanation. For the remaining participants the RT and the transformed proportion of errors were analysed. The RT to S1 is not included in the data because the participant has no time to prepare for this stimulus (suboptimal anticipation).

For the test phase (Block 7) a repeated measures analysis of variance (ANOVA) was used to analyse a 7 (Condition) x 6 (Key 2-7) design. The effect of Condition was significant, $F(6,120)=4.48$, $p<.001$

(see figure 2) indicating that there were differences in RTs for all blocks. The main effect for Key F(5,100)=6.79, p<.001 was significant and indicates that there were differences in RTs among the keys executed in the blocks. The average RT for each condition is represented in figure 2.

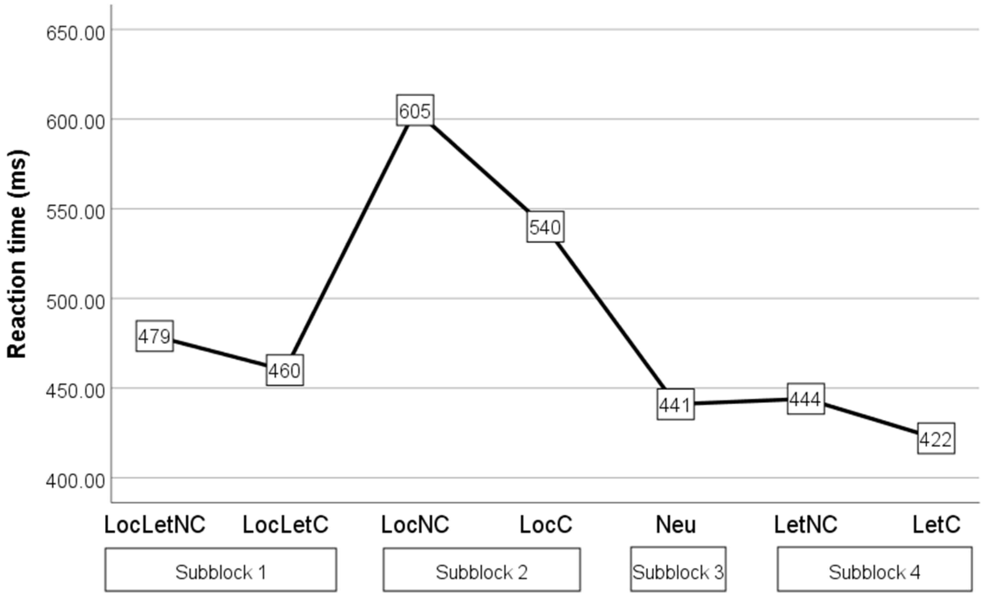

Figure 2: Reaction times (in ms) for condition LocLetNC, LocLetC, LocNC, LocC, Neu, LetNC and LetC.The LocLet conditions were tested in subblock 1, the Loc conditions in subblock 2, the Neu condition in subblock 3 and the Let conditions in subblock 4

For the arcsine transformed errors of the test phase the design that was used to analyse the LocLetNC and LocLetC conditions was 2 (Letter vs. X) x 2 (Non-corresponding vs. Corresponding) x 7 (Key). The same repeated measures analysis of variance (ANOVA) as for the RTs showed a significant main effect for the Letter vs. X, F(1,22)=7.20, p=.014. The effect of Correspondence F(1,22)=13.84, p=.001 was significant. For conditions LocNC and LocC a 3 (X vs. Non-corresponding letter vs. Corresponding letter) x 7 (Key) was used. The main effect for the X vs Non-corresponding letter vs Corresponding letter F(2,42)=1.16, p=.325 was not significant. The effect of Key F(5,105)=3.82, p=.003 was significant.

LocLet Condition

The test phase consisted of 7 Conditions. In the first and second Condition the non-corresponding and corresponding letters were shown (LocLetNC and LocLetC) in 4 placeholders. When comparing the LocLetNC condition with the LocLetC condition in a paired samples test, the RTs were shorter when the location as well as the letter corresponded, t(20)=2.55, p=.019. In figure 3 the average RT per key can be seen for both the non-corresponding and corresponding conditions.

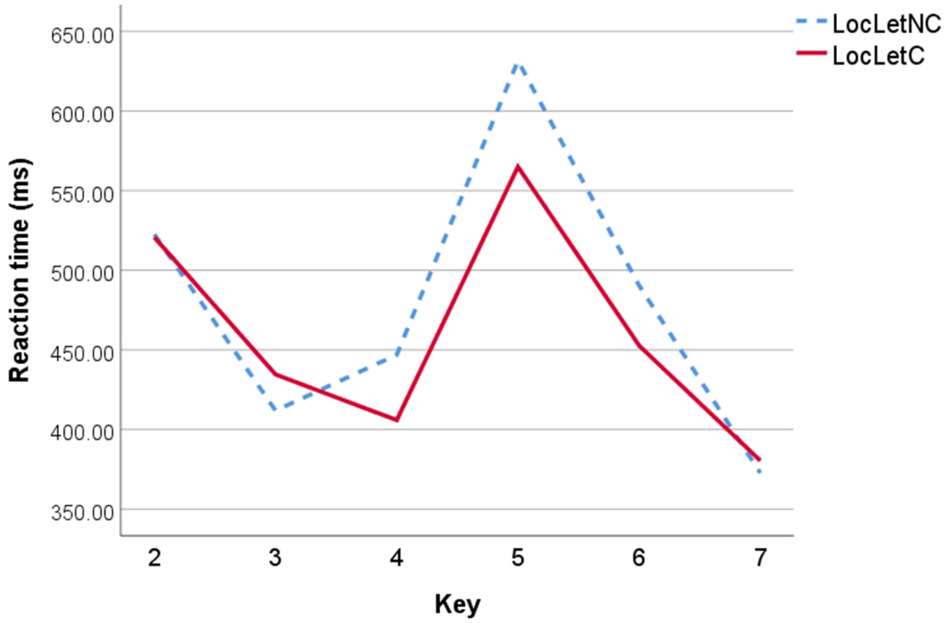

Figure 3: Average reaction times (in ms) in conditions LocLetNC and LocLetC per key.

Loc Condition

The LocNC and LocC conditions consisted of the 4 placeholders in which neutral stimuli ('X') where shown after S1 which were also either non-corresponding or corresponding in terms of the location. When comparing LocNC with LocC in a paired samples test the average RT was shorter when the location of the stimulus corresponded with the location of the key on the keyboard, t(20)=2.33, p=.030. In figure 4, the average RT can be seen per key.

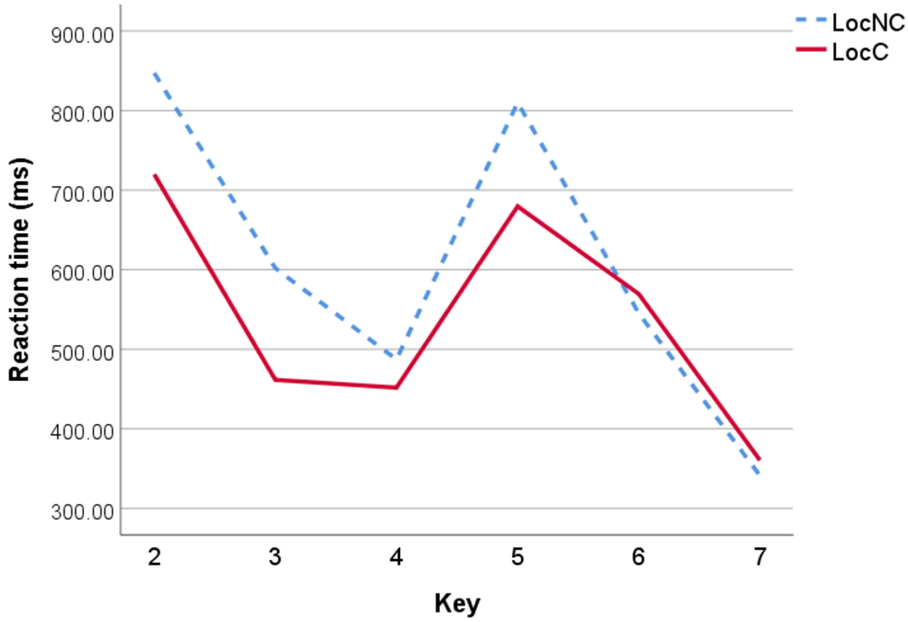

Figure 4: Average reaction times (in ms) in conditions LocNC and LocC 3 per key.

Neu Condition

The Neu condition was analysed with an univariate analysis of variance on the average RTs in this condition. Neu consisted of only neutral letters ('X') after S1. The effect was significant $F(1,20)=47.46$, $p<.001$ indicating that the sequences could still be executed. The average error percentage for the Neu condition was 4.9% which means that the participants did relatively have no more errors than in the conditions with letters, although only X's were shown after S1. The Key effect was significant for the errors in the Neu condition $F(6,132)=4.01$, $p=.001$. The percentage of errors differed from 3.9% on the first Key, to 4.4% on the seventh Key.

Let Condition

The LetNC and LetC conditions consisted of one placeholder with either incorrect letters after the S1 (75% of the letters) or correct letters (25% of the trials). When comparing LetNC with LetC the average RT in the LetC condition was shorter however this effect was not significant $t(20)=.944$, $p=.357$.

Discussion

The goal of this study was to determine what features of a visual stimulus are used when motor chunks are carried out in a DSP task. This was done in a DSP task to ensure the sequential representation on the basis of repeatedly performing key-press sequences. This allows for motor chunks to be made which means that S1 resulted in the execution of a whole chunk of responses. The observation of a Simon effect in this DSP task shows that not only the Response-Response association is used but the Stimulus-Response channel too. In this study the features of location and letter were taken into account. Is the Simon effect caused by the attention attracted by the onset of the stimulus or by the letter usage? Do the participants make use of the letter location or the letter identity (or in parallel)? To make sure that the Simon effect was indeed visible in this study, the RTs of the corresponding conditions were analysed and proved to be faster overall. Also the results showed the predicted effect of the motor chunks, functioning as one single response per chunk, as stated by Verwey (1999). The RTs even showed the three distinct processing phases as the slow response to the first stimulus represents the initation phase. This phase is followed by some faster responses referring to the execution key-presses. The segmentation of the chunks provided for the shorter RTs halfway through the sequence resulting in the visible concatenation point.

LocLet Condition

In the LocLet conditions there were 0% conflicting letters and 25% corresponding locations in four placeholders. When the stimulus location and letter are not of influence, both the conditions, of non-corresponding and corresponding should be equal in terms of RTs. The significant difference, analysed in the results section, indicated that the corresponding condition was indeed faster than the non-corresponding condition. This difference shows that the Stimulus-Response channel is still being used when motor chunks are used. This could indicate that the location as well as the letter is used in sequence execution.

Loc Condition

To analyse the importance of the location, the LocNC and LocC conditions were compared. In these conditions the stimuli after S1 were neutral (an ‘X’ instead of letters) and there were 25% corresponding locations in four placeholders. The significant difference indicates that the corresponding condition (LocC) was executed faster than the non-corresponding condition (LocNC). Also the percentage of errors was higher when the location did not correspond with the key. This indicates that the location of the presented stimulus does matter. The stimulus location is thus a feature that is used in sequence execution when chunks are used. The Stimulus-Response channel is still used and depends on the stimulus location.

Neu Condition

The Neu condition consisted of only X’s after S1 in one placeholder. This condition was analysed to determine whether the sequence could still be executed when only X’s were displayed after S1. The results indicate that the sequences could indeed still be executed and that the features of the stimuli were still being used. The average percentage of errors (4.9%) indicates that the participants made errors even when only X’s were shown.

Let Condition

The Let conditions consisted of 25% conflicting letters in one placeholder (so 75% of S2-S7 were other letters of EURO and were to be ignored). If the identity of the letter indeed matters for the participant, the RTs of the correct letters after S1 with 1 placeholder (LetC), should be shorter than the incorrect ones (LetNC). If the identity of the letter does not matter, the correct letters (LetC) and incorrect letters (LetNC) should not differ in terms of RT. Despite the faster RTs of LetC, this effect was not significant. This could indicate that the letter itself is less important in sequence execution. The letter is thus less important as the onset of the stimulus.

Conclusion

The present study shows that the Stimulus-Response channel is still used when motor chunks are used and that this channel is mostly dependent on the location of the stimulus. The study also shows that the execution of the learned sequences indeed changed over the successive blocks. In the beginning of the tasks, this was done by the reaction mode which changed to the chunking mode. Considering the significance of the location of the stimuli, it could be said that the Stimulus-Response channel is used and dependent on the location feature in sequence execution. Based on this evidence, the first hypothesis (The Simon effect is induced via the location of the stimulus) can be supported. While the data suggested that the letter is also of influence in sequence execution, this effect was not significant. The second hypothesis (The Simon effect is induced via the letter) is thus rejected. The usage of the Stimulus-Response channel that is demonstrated in this study is in line with earlier theory. The finding that this channel is dependent on the location of the presented stimulus is however an addition to the theory of motor sequence execution. This is a step closer to the understanding of motor automaticity but at the same time it raises further questions. The way of interpreting the stimulus features could be an obstacle for the present study. The use of letters could have an effect on the participants in terms of the identity. The cognitive processor could have more trouble in interpreting a sequence of colours than for instance a sequence of letters. The cognitive processor translates every stimulus that is presented into the associated response after which it prompts the motor processor to execute this response. If this cognitive processor is better in detecting certain optical traits, the process of translating this stimulus should take a shorter time when the stimulus contains these traits. This could even vary per person. To rule out this effect, in further research, the identity of the stimuli should be manipulated in a sequence task. The task could for example consist of a sequence of colours or numbers instead of letters to determine whether the same results are found.

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Appendix

1. Participant instructions

Participant instruction

Name study: The Simon task and DSP task V2

Duration: 3 hours, yielding 3 SONA credits

Period: March 26th – April 13th, 2018

Experimenter: Sil den Oude

Supervisor: prof.dr. W.B. Verwey

Dear participant,

You are about to participate in an experiment in which you are to perform a reaction time task. The instructions will be given by the experimenter and on the screen. In general, please stay concentrated at all times.

You will perform blocks of about 10-15 minutes separated by short breaks. Please remain in your cubicle during these breaks. At the end of each block, you will get feedback about how well you just did. Each time, wait for the experimenter to start the next block of the experiment.

In the last block, the task will be somewhat different. Stay especially focused during this block.

Making more errors will make the experiment last longer.

In order to prevent you being disturbed during the experiment, give your phone to the experimenter.

Good luck and thanks for your participation!

W. Verwey

2. Sequential order in DSP

forms indicate sequential order, only Z: random order

SeqDefA	SeqDefB	SeqDefC	SeqDefD	SeqDefZ	stimuli	responses
v	n	b	c	c	E	c
n	v	c	b	v	U	v
b	c	n	v	b	R	b
n	v	c	b	n	O	n
v	n	b	c			
b	c	n	v			
c	b	v	n			