

UNIVERSITY OF TWENTE.

Bachelor Thesis Psychology

**Context-dependency of Motor chunks
in a DSP go/no-go task**

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Abstract

Numerous studies have shown that performance is enhanced when the retrieval context matches the original context, initially studied in the verbal memory domain and broadened into the domain of motor skill learning. The present study was designed to address the role of practice concerning context-dependence of motor chunks in the DSP go/no-go task. The results showed that practice did not affect the sensitivity of contextual-dependencies; the groups with limited practice as well as extended practice did not rely on context features during performance. It is proposed that after extensive practice motor chunks develop triggered by the first presented stimulus. The limited practice group had sufficient training for the formation of motor chunks. Moreover, the study examined the impact of context-dependencies during the presentation of differently structured sequences (two different chunks vs. one repeated chunk). When participants had to reproduce a second different chunk context dependencies emerged which facilitated the retrieval of a representation. Based on the findings it can be assumed that the demands of the cognitive processor, which is responsible for loading and searching of motor chunks, is too high when confronted with a sequence made up of two different chunks. Therefore contextual features support the access of a chunk. It is only successful when the context in which motor chunks have to be retrieved is the same as during acquisition otherwise a motor chunk is not completely activated.

1. Introduction

The term “home court advantage” in for example a basketball match or a football match refers to the observation that a player’s performance is often better when the match takes place on his own team’s playing field than on the field of the opposing team (e.g., Schwartz & Barsky, 1977). The impairment in performance can be explained by the environment which is associated with the learned skills during training. This example is an illustration for contextual dependencies which develop during motor skill learning. The term context-dependency effect means that there is a better performance when the testing environment is similar to the original environment compared to when the environment is very different (e.g., Wright & Shea, 1991). The present study examines the role of contextual dependencies during motor skill acquisition in regard to the amount of practice. It specifically focuses on the context-dependence of motor chunks. Below the existing literature on context-dependent learning will be first discussed and the notion of motor chunks will then be explained.

1.1 Context-dependent learning

The idea that a situation in which the retrieval environment matches the original environment simplifies memory processes, is indicated in the concepts of context-dependent learning (e.g., Wright & Shea, 1991), procedural reinstatement (e.g., Healy, Wohlmann, Parker, & Bournem, 2005) and specificity of learning (e.g., Healy et al., 2005). The basic premise of context-dependent learning is that performance is enhanced when information available during training is also available during retrieval. More specifically, stored information is linked to the environment in which it was acquired. Therefore, the environment can serve as a cue for accessing learned material.

Numerous studies have demonstrated that the learning of information can be context-dependent (e.g. Eich, 1980; Godden & Baddeley, 1975). Initially, most of the experiments regarding the context-dependency effect were conducted in the verbal memory domain. A famous experiment was conducted by Godden and Baddeley (1975), in which participants had to learn lists of words. The word lists were transmitted through an ear piece and had been learned on dry land and underwater, followed by a recall test. The participants’ performance was better in the condition in which the

environment was the same in the learning phase as in the recall phase. There was no difference in performance whether participants learned underwater, or on dry land. Eich (1980) and Smith (1988) explained that the context-effect is a result of encoding. The environment is memorized as a part of the whole memory trace. By encoding, the environment can serve as a cue for recalling information from the memory trace. Tulving and Thomson (1973) implied within the encoding specificity that if information available at encoding is also accessible at retrieval facilitates memory.

In more recent years, other researchers have extended contextual dependencies to the domain of perceptual motor learning (e.g., Anderson et al., 1998; Wright & Shea, 1991). Wright and Shea addressed the question how contextual manipulations affect motor-skill performance. For this purpose, Wright and Shea trained their subjects on three 4-key sequences in which context stimuli were manipulated. They categorized environmental stimuli into intentional and incidental stimuli. Intentional stimuli were defined as those that are essential to task acquisition, whereas incidental stimuli are irrelevant for performance but can be associated with the task. In this study, the researchers focused primarily on the effect of incidental stimuli which shaped the context. Intentional stimuli were represented as numbers and horizontal positions on a display, which indicated the sequences participants had to perform. In contrast, to manipulate incidental stimuli, each sequence was paired with a combination of a particular display colour, a specific tone, a certain vertical position on a screen, and a particular placeholder shape. After participants had learned the key sequences, they had to reproduce them. The reproducing was accomplished either in the same or in a different context. When pairing of intentional and incidental stimuli was changed, the participant's performance was impaired: the percentage of erroneous responses increased compared to the condition in which the relation between incidental and intentional stimuli remained constant. These results gave evidence that contextual dependencies also develop in the motor domain; hence the learning of motor skills is context dependent.

Anderson, Wright and Immink (1998) conducted a follow up experiment in which the conditions were similar to that in Wright and Shea's (1991). They broadened their experiment focusing not only on erroneous responses, but also on reaction time, due to the fact that reaction time is more sensitive to

performance differences. The results showed that although performance is dependent on context reaction time as well as erroneous responses prove evident.

1.2 Motor learning and chunking

In every day life we are flooded with a lot of information from our environment. The capacity of our memory is limited and therefore the question arises how the information is dealt with. In order to find out, how our memory copes with this huge amount of information Miller (1956) introduced the idea of chunking. He explains that cognitive demands decrease, when stored information is structured more effectively. This means that instead of storing each element separately single parts are connected to one larger unit. This splicing of information is called chunking. Imagine you have to memorize a telephone number like for instance 2-1-5-6-4-3. Remembering each and every one of the six digits separately is harder than remembering a sequence of only three pairs of digits like 21-56-43. Chunking also was detected during motor learning (e.g. Verwey, 1999).

The discrete sequential production (DSP) task (Verwey, 1999) has proven an appropriate testing method for finding evidence of the emerging of chunks during motor skill learning. A decisive attribute of DSP is that motor sequences that have to be acquired are relatively short. In this case, participants had to learn two to six stimuli presented in a determined order. The stimuli consisted of four horizontally aligned placeholders. The task was to press a certain key on the keyboard after the corresponding placeholder had lit up on the screen. Learning of motor movement is comparable to learning of telephone numbers. Similar to the learning of a telephone number the separate elements – positions of keys on the number pad or keyboard- of a sequence are associated to each other. An interconnected structure called motor chunk emerges. Motor chunks are selected and executed as a single response to a stimuli or cue (Abrahamse, Verwey, & Jiménez, 2009).

During DSP tasks it can be observed that performance enhances due to practice. At the beginning of motor skill acquisition, participant's performance is very slow, because each separate sequence is executed individually. After extensive practice, participants execute the entire sequence in response to the first stimulus. Subsequent stimuli are then no longer required. The first given stimulus serves as a cue for processing the whole chunk. Through this process automation is attained (Verwey, 1999).

Wright and Shea (1991) came up with the idea that contextual dependencies become unnecessary with increased amount of practice. Hikosaka et al. (1999) supports this idea by proposing that dependency on context diminishes with increasing practice due to shifting from visual-spatial coordinates as trigger, to motor-based initiation. With increasing amount of practice motor sequences are executed automatically to the extent that they do not need much attention on contextual features.

Ruitenbergh et al. (under revision) examined the impact of practice on modulation of contextual dependencies. For this purpose participants had to learn on a DSP go/no-go task. This task serves as a qualified method for measuring the effect of practice on contextual dependencies. The DSP go/no-go task is similar to the DSP task except for stimuli being presented as a whole sequence instead of separately (see below for description of task). The results showed that participants with less practice performed worse when the sequences were shown in a colour they were not used to during skill acquisition. Participants with extensive practice showed no difference in performance with these switched colours. This study shows that contextual dependencies only emerge if motor sequences have not yet been automated.

Verwey (1996; 2001) proposed the idea of a dual processor, which contributes to motor sequence learning and explains how movement sequences are produced. The dual processor theory consists of two components: the cognitive processor and the motor processor. The cognitive processor selects motor chunks and plans executions while loading the motor buffer with information, whereas the motor processor simultaneously reads the codes of a motor chunk and selects them. Buffer loading can be understood as a kind of short term motor memory, which is responsible for the programming of sequences in advance of their execution if sufficient time is available (Henry & Roger, 1960; Sternberg et al., 1978). By learning a new sequence, initially every single element has to be selected separately. After extensive practice the motor buffer is consequently loaded with the same elements resulting in the emergence of motor chunks (e.g. Verwey & Dronkert, 1996).

Magnuson, Wright and Verwey (2004) dealt with the question whether manipulation of the incidental context has an impact on the loading and searching of the motor buffer. The researchers were interested in gaining insight on the influence of contextual manipulation on planning motor movements. For this purpose, the aim was to separate the movement into the cognitive processor,

namely the planning of movements, and the motor processor, namely the execution of a movement. In this study, participants had to learn one- and four- element sequences. The sequences involved either long or short durations of key-presses. Incidental stimuli were presented as specific tones. The pitch of the tone gave information about the key press duration. The task was to study stimulus cues to identify the requested movements as long as necessary to pre-program the response. After movement-preparation, a go signal appeared indicating that the movement should be carried out as soon as possible. After participants learned the sequences consisting of short and long key presses, participants had to perform the test phase, in which incidental stimuli were manipulated. The pitch of a tone could no longer be associated with the corresponding sequence. The results indicated that the manipulation of the incidental context has a deleterious impact on the search within the motor buffer. Changing of the incidental context aggravated the search of the motor buffer. This means that certain subsets of information did not get activated. As a consequence, a motor chunk could not get executed as one single response. In this experiment the impact of contextual dependencies in regard to the load within the motor buffer was investigated. The results showed that manipulating the context has no effect on organizing of information. Therefore, the motor buffer is still supplied with information which is essential for the formation of motor chunks. This study provides evidence of contextual dependencies in regard to the retrieval of motor chunks (Magnuson, Wright, & Verwey, 2004).

1.3 The present study

Although several studies concerning contextual dependencies were carried out focussing on motor chunks on the one and the effect of practice on the other hand, so far there has not been a study combining these aspects. The main purpose of this study is to find out if it makes a difference if the motor buffer is loaded either with two different chunks (e.g., bcn-vnc) or with a repetition of the same chunk (e.g. bcn-bcn) during motor sequence learning. It is taken into regard if contextual dependencies emerge and which role practice has to play in performance in shaping contextual dependencies.

Based on the dual processor theory (Verwey, 1996; 2001), consisting of the cognitive and the motor processor, it could be explained why the execution of a repeated motor chunk is facilitated. The task of the cognitive processor is to search for mental presentations and to plan actions. If the second

chunk is a repetition of the first chunk, then the cognitive processor does not have to apply demands for loading and searching a mental representation because it is still activated. In addition, the cognitive processor executes the sequences in parallel to the motor processor, because a new sequence does not have to be produced. Under the assumption that the same chunk does not get repeated, the cognitive processor has to load the motor buffer with a new representation. It can be supposed that when the cognitive processor has to load the motor buffer twice with two different representations, the execution of the sequences is prolonged. Concluding, that it is demanding for the cognitive processor to search for a new representation, it can be assumed that contextual features are applied. A new representation is retrieved by contextual features, which serve as a cue. In this case, contextual dependencies emerge.

In order to investigate the effect of practice on contextual dependencies of motor chunks, the DSP go/no-go task was used. After a sequence was shown a cross appeared indicating, that the participants should either react to the sequence or ignore it and wait for the next sequence. The task was to reproduce the sequences as fast as possible with as little mistakes as possible.

The sequences had to be learned in a specific colour and manipulated afterwards to advert to contextual dependencies. During the test phase participants had reproduce the sequences in three different context conditions. In the first condition sequences were presented in the same colour as in the practice condition (same context condition). In the second condition colours were swapped with the colours of other sequences from the practice phase (switched context condition). In the third and last case sequences were offered in a completely new colour, which was not used in the practice phase (new context condition). To test the demands of the cognitive during loading into the motor buffer, two sequences were presented: A sequence consisting of a repetition of the motor chunk whereas different sequence made up of two different motor chunks.

In this experiment two practice conditions with different learning durations were applied in order to investigate the effects of practice on contextual dependencies. Half of the participants were assigned to a short practice phase (limited practice phase), whereas the other half had to go through a longer practice phase (extended practice condition).

Based on the above mentioned experiments and their results some hypotheses can be formulated. First, Wright and Shea (1991) manipulated contextual dependencies by changing the relation between intentional and incidental stimuli. The results proved that performance diminished when the context in which the motor skill was learned was not the same as during the test phase. In addition they thought it was possible that practice plays a role in the modulation of contextual dependencies. Ruitenberget al. (under revision) conducted an experiment, which dealt with the influence of practice on context. It was shown that practice has an effect on the context-dependency. After sufficient practice tasks were executed automatically without the need of paying attention to contextual information. Therefore, it can be concluded, that contextual dependencies only emerge in the short practice condition in this study. When participants of the short practice condition have to perform in the switched or new context condition their performance is worse than in the same context condition. Participants of the extended practice condition show no change in performance within the three context conditions.

Secondly a study of Magnuson, Wright and Verwey (2004) analyzed which impact contextual dependencies have on the performance of the motor buffer. They assumed that changes of context obstruct the searching for a motor chunk but do not hinder the load of the motor buffer. Besides, the dual processor theory (Verwey 1996; 2001) explains that the cognitive processor can not cope with the demands of a different sequence and therefore has to fall back to using the context. Therefore, it can be hypothesized that context dependencies only emerge during the execution of a second not repeated chunk within the extended practice condition (motor chunks does not develop in limited practice condition due to not sufficient training).

2. Method

2.1 Subjects

Forty students (31 female, 9 male) of the University of Twente served as participants in this experiment. Except for two participants, all were students of the Faculty of Behavioral Sciences. The participants' age ranged from 18 to 25 years with a mean age of 20 years. According to the results of the Annett Handedness inventory (1970) 36 participants were tested to be right handed, whereas 4 participants showed no hand preference. All participants were healthy and did not suffer from colour blindness, dyslexia or attention deficit hyperactivity disorder. Subjects received either student credits or participated voluntarily.

2.2 Apparatus

For stimulus presentation and data registration E-Prime 2.0 © was used, running on a Pentium IV class PC. Stimuli were presented on a 17 inch Philips 107 T5 display, and a standard keyboard was used for giving responses.

2.3 Task

Subjects were informed to place their little, ring, middle and index finger of their left hand on the c, v, b and n keys of the keyboard. In the centre of the computer display, four horizontally aligned squares emerged, which functioned as placeholders for the stimuli. The placeholders were identified by a white edging presented against a black inside and a black background. In addition, a white fixation cross appeared on the monitor that was centrally arranged above the placeholders. The squares lit up in a determined order one after another building a sequence, either in yellow or blue. The participants had to remember the presented order of the sequence until they received a signal of the fixation cross to reproduce the sequence. A go-trial, signified by the colour green, informed the participants to respond to the enlightened stimuli, while pressing in correspondence to the placeholder the respective key, e.g., by enlightenment of the rightmost placeholder n is the appropriate key. Red indicated a no-go trial, which asked the participants to wait and attend until a new trial was given. Figure 1 illustrates how the sequences were presented on a computer screen in the DSP go/no-go task.

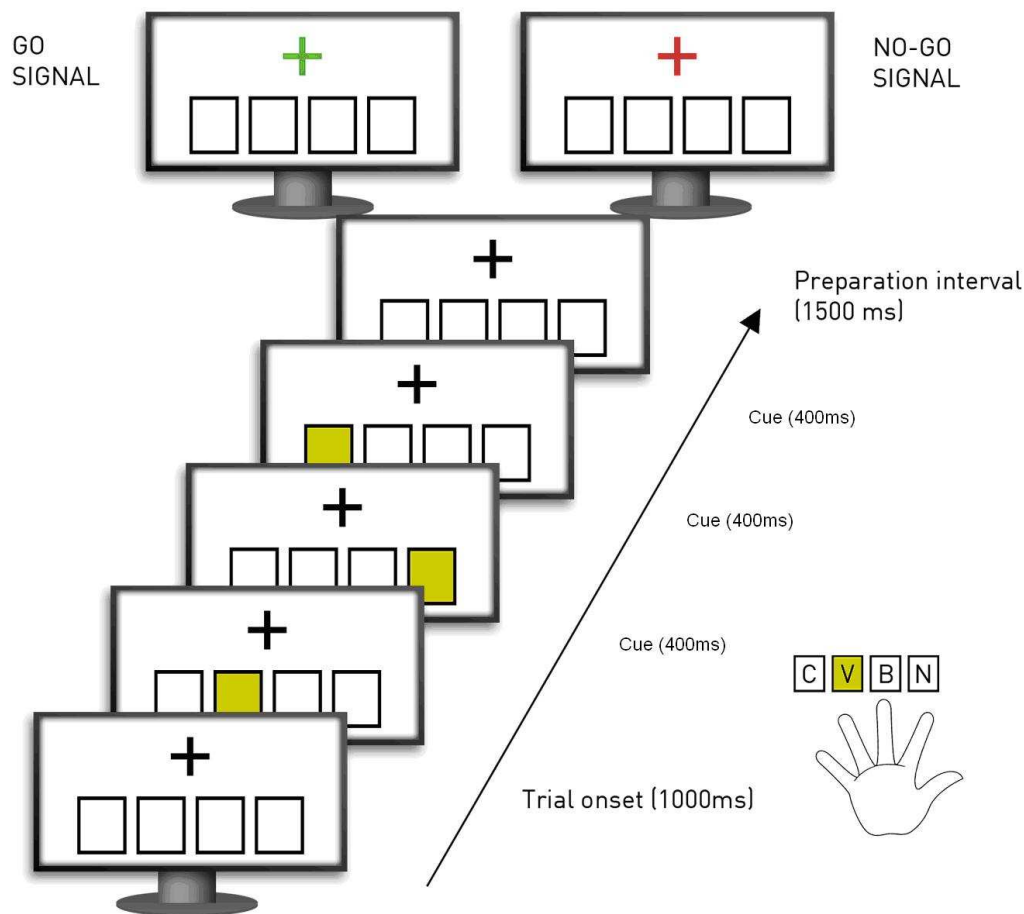


Figure 1: Illustration of a 3-key sequence presented in yellow. Participants had to place the fingers of the left hand on the keyboard. After viewing the whole sequence a signal indicates how to respond (red=wait and green=respond), The task required pressing in correspondence to the placeholder the appropriate key, in this case v-n-c.

After participants responded correctly a new sequence was provided, and so on. A sequence was made up of three successfully enlightened placeholders and responses in a consecutive order. If participants correctly reproduced a sequence, a positive feedback was given. Wrong key presses were indicated by counting up to the number of erroneous responses at the end of each sequence. After a premature response participants were informed that their response was too early and they had to wait until the fixation cross got coloured. In total subjects learned four sequences of three key presses, namely vnc,

bcn, nvb and cbv. Two of these sequences were presented in blue and two in yellow in a counterbalanced order across and within participants.

In the test phase participants had to respond to 6-key sequences, the instruction and procedure remained the same. The sequences the participants learned in the practice phase were combined in two ways. The 1×6 sequence was made up of two different trials, namely vnc, bcn, nvb and cbv that were intercombined (e.g., bcn-vnc, nvb-cbv), and the 2×3 sequence consisting of two trials paired with each other (e.g., bcn-bcn, nvb-nvb). In this experiment intentional stimuli were identified by the enlightened placeholders, because they were essential for the execution of the task, while participants had to respond as fast and accurately to the represented stimuli. The colours of the placeholders served as contextual (incidental) features. To test contextual dependencies, participants had to perform the sequences in different context conditions, namely same, switched and new context. In the same context condition the 6-key sequences were presented in either yellow or blue. During the switched condition, the blue coloured sequences in the practice phase were filled with yellow in the test phase and vice versa. The new context condition included a third colour, namely red. In addition, two colours were combined in one sequence, e.g. bcn presented in blue was associated with vnc presented in yellow. The order of the various test conditions was counterbalanced over and within the participants.

2.4 Procedure

The experiment took place at the lab of the Cubicus building at the University of Twente. At the start of the experiment all participants were asked to read and sign an informed consent. In addition they had to fill out the Annett Handedness Inventory (1970) to ensure that all participants were right-handed. As mentioned above four participants were tested to be ambidexter, but due to the fact that there were no essential differences in performance in comparison to right-handers the results could be included into the analysis. The subjects then entered the testing room, where they had to read a detailed written instruction and a summarized instruction that appeared on the monitor before the experimenter could start the task.

Each individual stimulus was presented for 400ms. A practice block consisted of 40 repetitions of 3-key sequences and 24 no-go trials. During the repetitions 30 sec breaks were arranged for relaxation. Half of the participants completed one practice block (i.e., the limited practice group), while the other half completed four blocks, hence 160 repetitions per sequence (i.e., extended practice group). After participants finished the practice phase they were asked to fill in a questionnaire to test their knowledge of the learned chunks. The questionnaire examined both recall and recognition. Further participants could inform about their comments regarding the experiment.

The practice block was followed by one test block, that included 48 sequences that had to be executed and 12 no-go trials.

Finally, the researcher thanked the subjects for their participation, and those that were registered in the student system received their credit points.

3. Results

Sequences which consisted of one or more erroneous responses were discarded from the analysis. For every participant the mean reaction time (RT) and the proportion of erroneous responses (PC) per key within the sequence in each block was assessed. RT was calculated as the time participants needed between stimulus presentation and response through pressing the respective key. PC can be defined as percentage of not correctly executed key presses. Analysis of variance (ANOVAs) with repeated measures were performed to identify factors that are responsible for potential differences between the mean of different groups. The data from the practice phase and test phase were analyzed separately.

3.1 Practice Phase

For the analysis of the limited practice condition an ANOVA with repeated measures with Key (3) was used. The results showed that there was a significant effect of Key with $F(2,78)=157.76$, $p<.001$, which indicated that responses to some keys were faster than responses to others. In more detail, reaction times decreased with position in the sequence, that is, responses to key 1 were slower than responses to key 2, and reaction times for key 3 were the fastest (462.5ms vs. 307.92ms vs. 259.88ms, for Key 1, Key 2 and Key 3, respectively).

For the extended practice condition an ANOVA with repeated measures with Block (4) and Key (3) as within-subject variables was performed. The data of the extended practice condition also revealed a significant effect of Key, $F(2,38)=52.83$, $p<.001$. Similar to the limited practice phase, performance increase across the keys (405.36ms vs. 273.76ms vs. 230.49, for Key 1, Key 2 and Key 3, respectively). Furthermore the data showed that the performance improved across the blocks, because reaction times decreased $F(3,57)=36.23$, $p<.001$ (367.73ms for block 1, 289.7ms for block 2, 285.02ms for block 3 and 270.38 for block 4, respectively). A Block \times Key interaction could not be found, $F(6,114)=2.59$, $p=.069$, indicating that all keys were affected in the same way by the practice blocks.

In order to test for differences between the two practice groups (limited vs. extended) an ANOVA with repeated measures on the first practice block was run with the within-group variable

Key (3) and the between-group variable Practice (2). Evidence showed a main effect of Key, $F(2,76)=154.14$, $p<.001$, with an decrease in reaction time across the keys (462.5ms vs. 307.93ms vs. 259.88, for Key 1, Key 2 and Key 3, respectively). In addition, the reaction time gave no evidence that there is a difference in the execution of the keys between both groups, thus no interaction effect was found, $F(2,76)=.11$, $p=.840$. Based on the results it can be assumed that the performance of both groups did not differ significantly, $F(1,38)=3.66$, $p=.063$.

3.2 Erroneous Responses during the practice phase

An error analysis was performed to examine the accuracy of the participants` performance. For this purpose the proportion of errors was calculated in the practice blocks. For the limited practice condition a repeated measures ANOVA with Key (3) showed that the proportion of errors differed across the keys, $F(2,78)=11.07$, $p<.001$ (3.5% vs. 4.9% vs. 4.3%, for the first, second and third key, respectively).

In order to analyze the proportion of errors for the extended practice condition an ANOVA with the within-variables Block (4) and Key (3) was used. The results indicated no significant main effect of Key, $F(2,38)=3.28$, $p=.078$, no significant main effect of Block, $F(3,57)=1.1$, $p=.349$, and no interaction effect of Block \times Key, $F(6,114)=1.$, $p=.411$.

To account for possible differences between the two practice conditions, a repeated measures ANOVA on the first block with Key (3) and the between-group variable Practice (2) was performed. The data revealed different mean averages of errors between the keys, $F(2,76)=11.72$, $p<.001$. Most errors were made on key 2, with 4.9% (3.5% for Key 1 and 4.3% for Key 3). Furthermore there was no main effect of Practice, $F(1,38)=1.24$, $p=.273$ or interaction effect of Practice \times Key, $F(2,76)=3.3$, $ps>.05$.

3.3 Test Phase

To test the effects of context manipulations of motor chunks in regard to the amount of practice, a repeated measures ANOVA with Context (3), Sequence (2) and Key (6) as within subject-variables and Practice (2) as between-subject variable was performed. The results showed that performances differed in the various context conditions, $F(2,62)=3.75$, $p<.05$. Figure 2 shows that reaction time for the new context condition is the longest in comparison to the same and switched context condition.

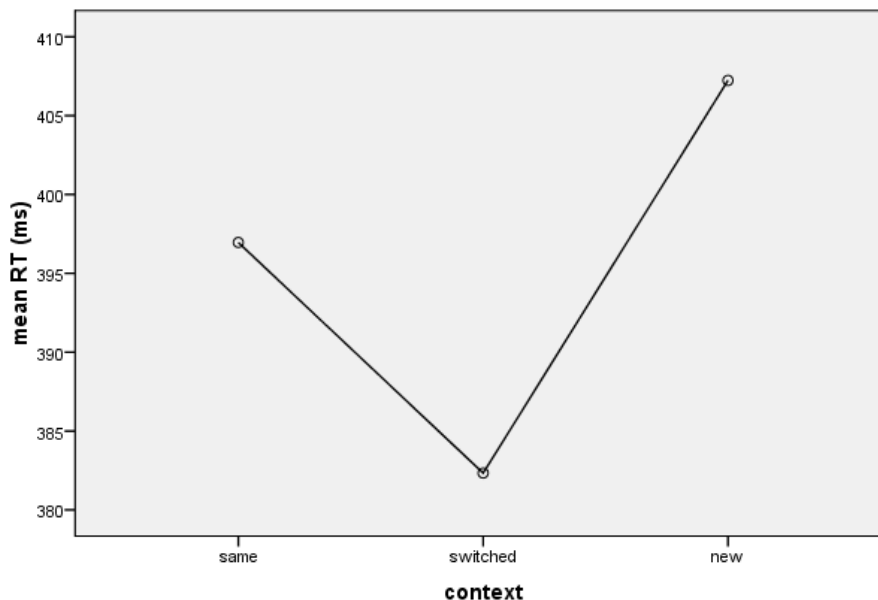


Figure 2: Reaction times within the context conditions

For closer examination, planned comparisons were performed. First, a planned comparison between the same context and switched context condition showed that performances did not differ significantly, $F(1,33)=3.04$, $p=.091$. The second planned comparison between the same and new context condition revealed no main effect of Context, $F(1,32)=.7$, $p=.41$. Therefore, the differences in performance within the context conditions are due to the differences between switched and new context condition. A planned comparison between switched and new context condition proved evidence that performance is in one context condition better than in the other one, $F(1,34)=10.12$, $p<.01$. This effect was not

further analyzed because it was not of interest. The present experiment focuses solely on performance differences between same/switched context and same/new context.

The overall ANOVA analysis revealed a significant effect of Key with $F(5,155)=20.27$ $p<.001$, indicating that specific keys have a longer reaction time than other keys (see Figure 3). Moreover, the results showed that participants performance was better during the execution of a sequences consisting of a repetition of a motor chunk than the execution of a sequence made up of two different motor chunks, $F(1,31)=22.67$, $p<.001$ (see Figure 3). Figure 3 illustrates that reaction times on key 1 and key 4 are the longest especially in the sequence made up of two different motor chunks, therefore indicating a Key \times Sequence interaction effect with $F(5,155)=6.253$, $p<.01$.

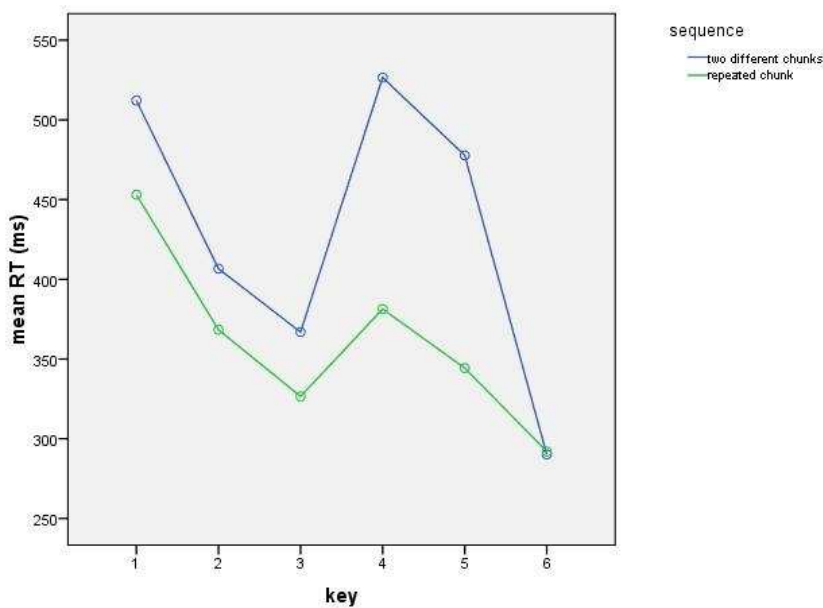


Figure 3: Reaction times for keys within the sequences

Neither a Sequence \times Context interaction effect nor a Sequence \times Key \times Context interaction were found, with $F(2,62)=1.55$, $p=.223$ and $F(10,310)=2.03$, $p=.124$, respectively, showing that both sequences and all keys within the sequences were affected by context in the same way .

Further analysis showed that there was neither significant effect of practice $F(1,31)=1.52$, $p=.227$, nor a significant Practice \times Context interaction effect, $F(2,62)=1.84$, $p=.171$. Therefore the

amount of practice did not enhance performance or modulates the results within the context conditions.

3.4 Erroneous Responses during test phase

For the test phase an error analyses was performed to examine the effects of context and practice on the accuracy of participants` performance. For this purpose a repeated measures ANOVA with Context (3), Sequence (2) and Key (6) as within subject-variables and Practice (2) as between subject-variable was run. The results revealed a significant effect of Key, $F(5,190)=86.69$, $p<.001$, indicating that error proportions were not distributed proportionally across the keys (1.05% for key 1, 1.34% for key 2, 1.97% for key 3, 2.91% for key 4, 3.46% for key 5 and 3.38% for key 6). Furthermore, a significant effect of Sequence with $F(1,38)=77.68$, $p<.001$ indicated that participants made proportionally more errors during the execution of a sequence of two different chunks than during the execution of a sequence consisting of a repetition of a chunk (3.23% vs. 1.47%, respectively). Moreover, a Sequence \times Key interaction was found, $F(5,190)=28.24$, $p<.001$ in which most errors were made on key 5 in the sequence with two different chunks (Figure 4-6). In addition, the Sequence \times Key interaction effect was affected by context, $F(10,380)=2.59$, $p<.05$. The Figures 4-6 illustrate that most errors were made on key 5 within the sequence made up of two different chunks. This effect was especially found in the switched context (Figure 5).

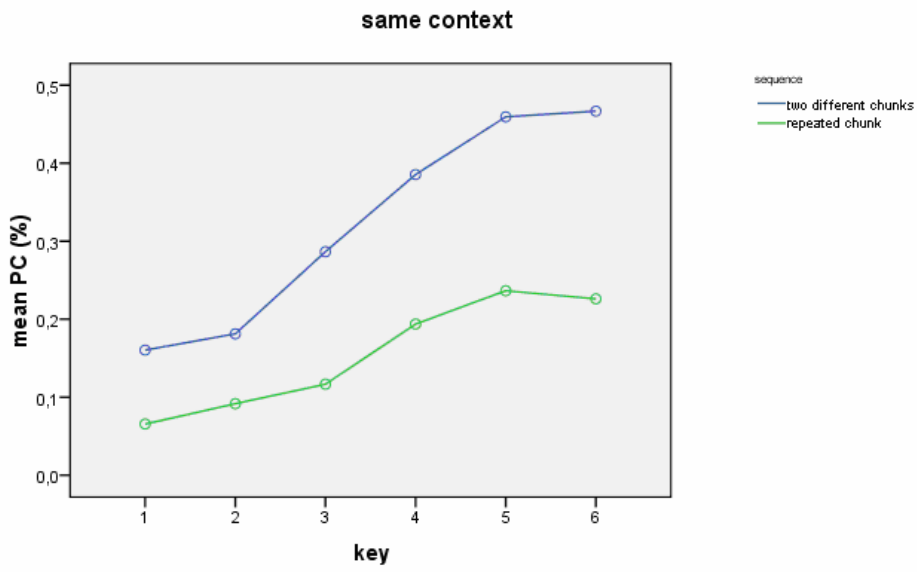


Figure 4: Mean PC on Key across the sequences in the same context

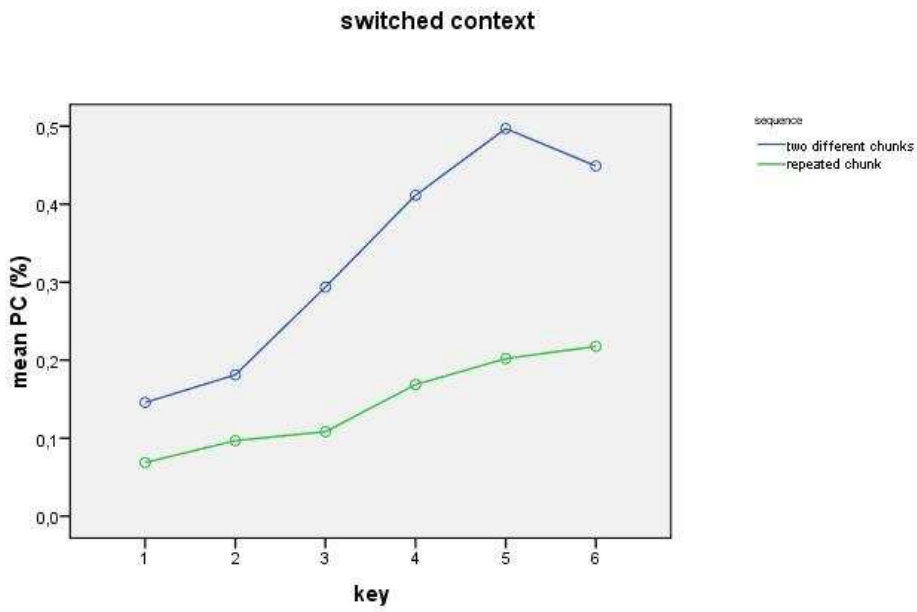


Figure 5: Mean PC on Key across the sequences in the switched context

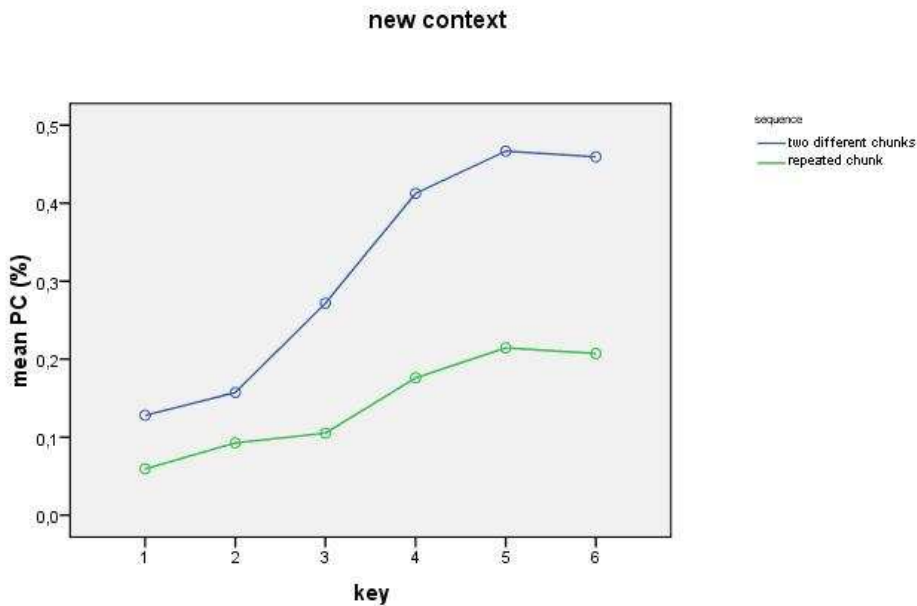


Figure 6: Mean PC on Key across the sequences in the new context

Finally, the data revealed that participants aligned to the limited practice condition made as many error as participants of the extended practice condition, $F(1,38)=.02$, $p=.887$. Performance was not affected by context, $F(2,76)=2.95$, $p=.066$.

3.5 Questionnaire

For the analysis of the questionnaire a repeated measures ANOVA with Method (2), Sequence (4) as within subject-variables and Practice (2) as between subject-variable was used. Method (2) indicated that participants had to recall and to recognize the sequences. The results of the questionnaire revealed that participants correctly recalled as many sequence as they recognized, $F(1,38)=.73$, $p=.397$. Furthermore, the data showed that practice had no influence on the amount of correctly recalled sequences, $F(1,38)=1.08$, $p=.306$, nor on the amount of correctly recognized sequences, $F(1,38)=1.95$, $p=.171$. Table 1 shows that the distribution of correctly recalled and recognized sequences is proportionally across the two practice conditions.

	Limited condition		Extended condition	
	Recall	Recognition	Recall	Recognition
None correct	0	1	0	2
One correct	3	3	1	0
Two correct	7	8	6	3
Three correct	3	2	4	6
Four correct	7	6	9	9

Table 1: Number of correct responses within the conditions

Discussion

The present study aimed to reproduce and deepen knowledge concerning the question whether contextual manipulations affect motor chunks and how these context-effects are modulated by practice. For this purpose the DSP go/no-go task was used in which participants had to respond as fast and accurately as possible to sequences after receiving the go-signal. In order to measure context-effects of motor chunks two differently structured sequences (two different chunks vs. one repeated chunk) and three different context manipulations (same, changed and new context) were used. Finally, to test the effect of practice on context-dependency participants were aligned to two practice conditions of different lengths (limited vs. extended). Based on the results two major conclusions can be made. First, results showed no evidence that participants' performance was primed externally by contextual features after limited practice. Second, the retrieval of the second motor chunk within a sequence consisting of two different motor chunks is impaired and therefore context-effects emerge. The findings of the present study will be discussed in more detail below.

It was hypothesized that contextual dependencies diminish with the progress of practice (e.g., Wright & Shea, 1991), because internal representations, namely motor chunks are formed, which do not require paying attention on contextual features. Against the expectation it could not be proven that performance in the group with limited practice depends on contextual features. Therefore, it can be assumed that performance is not context dependent. There has to be a different trigger for the response. Tubau, Hommel and López-Moliner (2007) explained that after sufficient practice there is a change in the trigger of the response. Performance is no longer externally driven (cued by the environment, like in this case by colors), but instead internally driven cued by motor chunks. Verwey (1999) noticed that after extensive practice single elements of a sequence are formed to a motor chunk. This eases execution of sequences due to the fact that a sequence is processed as a single element. The first stimulus of a sequence retrieves the whole sequence.

This finding coalesces with the results of the extended practice group, seeing as there is no indication for context triggering responses. Though the question remains as why performance was not externally driven, when extensive practice was missing. When viewing the results no difference in the speed of reaction time between the limited and extensive practice groups could be observed. It can

essentially be assumed that both groups made the same progress. This can also be proven in the questionnaire. The limited practice group recalled and recognized as many sequences as the extended practice group. In this case both groups developed motor chunks. The unevenly distributed temporal motor pattern is an indication of the emergence of motor chunks. The increase in reaction time revealed that a motor chunk was retrieved, whereas the decrease showed that the motor chunk was processed in one response. In both groups the trigger was motor-based because a single practice block could be sufficient for the acquisition of motor chunks. A distinctive attribute of motor chunks is their robustness (Verwey, 2001). Verwey concluded that after extensive practice motor chunks become reinforced enough to be utilized in alternative contexts.

Moreover Davies and Thomson (1988) explained that contextual dependencies are intensified when the context is pointed out to the participants. In the present study, participants were not explicitly instructed to pay attention to the presented colours and therefore they had a lower impact on the results.

By analyzing Ruitenbergs et al. (under revision) experimental set-up additional indications are found showing that performance is internally driven in this experiment. To begin with sequences of different lengths were utilized. In the present study four sequences consisted of 3-keys, opposed to two sequences consisting of 7 keys in Ruitenbergs et al. study. It probably takes longer and is more complicated and cognitively demanding to establish motor chunks from longer sequences. Secondly, task difficulty (3 keys vs. 7 keys) could serve as a mediating factor for the modulation of contextual dependencies (Wright & Shea, 1991). Wright and Shea demonstrated that context-dependencies emerge during the execution of four-key sequences and not during three-key sequences. Context dependencies assumably are more extensive for longer sequences, which would have to be verified by comparing these two sequences directly in a single experiment.

This study especially focused on context dependencies of motor chunks. It was hypothesized, that when participants had to perform a sequence consisting of two different motor chunks the demands necessary to access the second chunk were higher in comparison to a sequence made up of a repetition (s. dual processor). Due to a sequence consisting of two different motor chunks being more cognitively demanding for loading the motor buffer, context serves as a support for the retrieval and

accessing of the chunk. It was assumed that this effect can only be observed in the extended practice condition because extensive practice causes the formation of motor chunks. Due to the fact that motor chunks developed in both practice conditions, the following assumptions can be applied to both practice conditions. The analyzed results underline the inquired supposition. Results showed that the cognitive processor was overwhelmed with the load of a second motor chunk within a sequence differently structured. The context facilitated the retrieval process.

Suprisingly, only increase in erroneous responses and not an elongation in reaction time was observed, although Anderson, Wright and Immink (1998) mentioned that reaction time is sensitive in measuring context-dependencies. In addition, the increase of errors could be recognized for a certain key. As already mentioned, incorrectly executed sequences were removed from the analysis of reaction time and were evaluated in the analysis of erroneous responses. There is no context effect in reaction time seeing as it is irrelevant if the sequence is executed in the same, switched, or new context condition if the motor chunk was selected correctly. The increase of erroneous responses can be explained by the new and changed context inducing wrong expectations for the participants, causing motor chunks not to be loaded completely or correctly. The manipulation of context leads to elements of the motor chunk not being activated. This explains why certain key-presses produced more errors than other. The motor chunks could not be executed as one single response cued by the first stimuli and therefore every element had to be reproduced individually.

Verwey (2010) distinguished between three phases during the production of DSP sequences which are suitable for the present findings. The sequence initiation, characterized by the response time on the first key, the concatenation phase, which indicates the transition from one motor chunk to the next and the execution phase in which the motor chunks are executed. In this experiment it can be assumed that only the concatenation phase was impaired after manipulating the context. The transition to the second differently structured motor chunk was aggravated and therefore contextual dependencies developed. Sequence initiation remained unaffected after a contextual change because the load of the first chunk is not cognitive demanding. Furthermore a change in the environment had also no impact on the execution phase due to the fact that the presence of a motor chunk determines whether a sequence gets executed correctly or not, the environment is irrelevant. Thus it can be

supposed that the cognitive processor is affected, whereas the motor processor executes without impairments. The results match those of Magnuson, Wright and Verwey (2004) which gave evidence that after context manipulation not all elements of motor chunk were activated.

The fact that performance is enhanced when material available at training is accessible at retrieval is proven by the encoding specificity principle (Tulving & Thomson, 1973). Erroneous responses increased due to the manipulation of context. The change of color and the implementation of a new color altered the original context resulting in an impairment in loading and searching the motor buffer.

In summary, the experiment shows that practice has no effect on the modulation of context. It should be mentioned, that this conclusion should be viewed skeptically, seeing as it is not certain what caused this result. It is possible that motor chunks formed rapidly due to the minor length of the sequences. In order to judge the effect of practice more accurately a follow-up experiment would be necessary. It would not only be interesting to examine if practice has an effect on context dependencies, but also after how much practice this effect would show up. Several practice control groups would be reasonable for such an experiment. Also, the influence of task difficulty should be taken into account more specifically and combined with the influence of practice. More precisely it should be questioned how much practice for sequences of different lengths is necessary to form context dependencies.

Secondly it can be assumed that the cognitive processor is overstrained by two different chunks forming a single sequence. Therefore the context is utilized as a support for the processor helping with the accessing and handling of motor chunks. Seeing as only a single suitable representation is read if the context is the same as the one in which it was acquired it can be concluded that the retrieval of a representation is context dependent.

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